INCENTIVISING THE RECOVERY AND UTILISATION OF CONSTRUCTION AND DEMOLITION WASTE

Daniel Marc Rossetto

A thesis submitted for the degree of Doctor of Philosophy

The University of Adelaide

Faculty of Sciences, Engineering and Technology

School of Architecture and Civil Engineering

March 2024

TABLE OF CONTENTS

Abstract

This thesis analyses the question of how to improve incentives for resource recovery in construction and demolition waste practice. It is a *thesis by publication*, containing five individual portfolio papers published in peer reviewed academic journals during 2023 and early 2024, deploying a hybrid qualitative and quantitative (longitudinal) approaches.

The thesis contains five main findings. Firstly, that economic incentive mechanisms used to motivate firms to manage externalities in construction and demolition waste can be classified in three main groups: revenue support, cost-of-capital support and negative externality levy mechanisms. Secondly, that incentives linked to greenhouse gas abatement can drive positive resource recovery outcomes as a co-benefit. Thirdly, that unilaterally designed mechanisms like border carbon adjustments, which offer potential as an incentive mechanism, can generate controversy among affected jurisdictions, jeopardising the long-term sustainability and credibility of the investment signals. Support for this finding was evident during the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC)[1], with parties expressing concern over the EU's carbon border adjustment mechanism, affirming understanding that incentive mechanisms designed to induce investment into long-lived infrastructure assets need to be perceived by firms as sustainable. Fourthly, that there is an important role for voluntary action by private firms in the pursuit of resource recovery and the reduction of negative externalities associated with waste management. The effectiveness of voluntary action, though, is linked to what customers want and are prepared to pay. In cases where customer preferences favour environmental protection, firms may engage in innovation to capture market share by increasing competitiveness. In addition, the research found that simultaneous access to two or more support mechanisms did not necessarily invalidate an activity's need for those incentives nor did it always amount to greenwashing. Within the fifth portfolio paper, this research provides a framework for quantifying the equivalence of incentive mechanisms as a financial value per unit of positive externality.

[1] Carbon Pulse. *COP28: FEATURE – Complaints over unilateral trade measures threaten progress in crucial climate talks*. Published 7 December 2023. URL https://carbon-pulse.com/242926/.

The research found that developing incentives is challenging because climate change, waste management, resource recovery and recycling are globally connected problems. Negative impacts and supply chain relationships overlap political boundaries. Therefore, solutions implemented in one jurisdiction may well resolve problems simply by shifting them to another location and creating harm elsewhere. Equally, firms operating across jurisdictions can identify and even exploit the regulatory arbitrages that policy variation opens up. This underscores the role for regional and multilateral cooperation, challenging as it may be to implement.

Further research is recommended. The first area is exploration of contemporary issues in the design of multilateral sectoral mechanisms that create incentives, as alternatives to border carbon mechanisms. The second area is methods to integrate assessment of project and activity-level additionality into methodologies for labelling of sustainable finance. The third area is preparation of qualifications to Coase's Theory and the Porter Hypothesis theories, or the development new theories. A limitation of this thesis was its focus on steel, therefore future research is recommended into other construction materials.

Statement of originality

I, Daniel Marc Rossetto, certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree. The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works. I give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time. I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship and a Divisional Scholarship by The University of Adelaide.

Signed:

Daniel Marc Rossetto

Date: 14/03/2024

Preface

This thesis fulfils an ambition I have held since I was an undergraduate in 1996 completing my honours dissertation, which was to do a PhD. At the time, I was uncertain about my preferred topic of research. I felt like I needed to gain more professional experience to help me identify a suitable topic. I then thought I would be best placed to work for five or so years before returning to research. That was over 20 years ago. As I enrolled for this PhD, I had several ideas for my research and the area of incentives for resource recovery and utilisation – the subject of this thesis - was one. I was introduced early on in the process to the portfolio of publications route. I was attracted to this idea for several reasons. The first was the opportunity to get continuous feedback from peers along the way, as I wrote up my research. This provides a safeguard from potential bias that may have built up during years accumulated in practice. It might also prove beneficial if I were to choose an academic career pathway after my PhD, as the experience of publishing in peer-reviewed journals is an integral part of one's responsibilities in that field. The second point of attraction was extending the readership of my work from those prepared to read an 80,000-word thesis to those interested in circa 7,000-word subdivisions at a time, which I figured would likely be more. Finally, I felt the chances of achieving greatest impact would be achieved through choosing primarily open access means of publication, increasing dissemination opportunities accordingly. Consequently, it is with pleasure that I present this thesis as the final result of my endeavours to explore this innovative yet non-traditional approach to a PhD.

Acknowledgements

I dedicate this doctoral research to my late mother, Dr. Marietta Sandra Rossetto (née Paparella, 1946-2022), who obtained her Ph.D. from The University of Adelaide in humanistic sociology. She provided me with all the inspiration, wisdom, guidance and enthusiasm I needed to do this work. I can think of no better way to honour her than to follow in her footsteps.

I would like to thank my father, Silvano Rossetto, for his support during the course of this PhD. I would also like to thank my supervisors, Professor Jian Zuo and Professor George Zillante, for their invaluable guidance and support; and the School of Architecture and Civil Engineering within the Faculty of Sciences, Engineering and Technology at The University of Adelaide for providing me the opportunity to undertake the research presented in this thesis.

List of abbreviations

Abbreviations used throughout this thesis and the portfolio publications are provided below:

ACCU – Australian Carbon Credit Unit

AUD – Australian Dollar

BCA – Building Code of Australia

BF – Blast Furnace

BOF – Basic Oxygen Furnace

CBA – Cost-Benefit Analysis

CBAM – Carbon Border Adjustment Mechanism

CDM – Clean Development Mechanism

C&D – Construction and Demolition

CE – Circular Economy

CEFC – Clean Energy Finance Corporation

CH_4 - Methane

COP28 – 28th Conference of the Parties to the UNFCCC

CORSIA – International Civil Aviation Offset Mechanism

CPM – Carbon Pricing Mechanism

CSR – Corporate Social Responsibility

EAF – Electric Arc Furnace

EPD – Environmental Product Declaration

ERF - Emission Reduction Fund

ESG – Environmental, Social and Governance

EU – European Union

EUA – European Allowance

EU ETS – EU Emissions Trading System

EUR – Euro

HREC – Human Research Ethics Committee

GDP – Gross Domestic Product

GHG – Greenhouse Gas

GSAA – Global Sectoral Steel and Aluminium Arrangement

ICAO – International Civil Aviation Organisation

IRA – Inflation Reduction Act

LGC – Australian Large-scale Renewable Energy Certificate

LME – London Metal Exchange

MBM – Market-based Management

MW - MegaWatt

MWh – MegaWatt Hours

NDC – Nationally Determined Contribution

NEM – National Electricity Market

NPV – Net Present Value

ODA – Official Development Assistance

OECD – Organisation for Economic Cooperation & Development

RIS – Regulatory Impact Statement

SDG – Sustainable Development Goal

TCFD - Taskforce for Climate-related Financial Disclosure

tCO_2e – Tonnes of Carbon Dioxide-equivalent GHG

UN – United Nations

UNFCCC – UN Framework Convention on Climate Change

US – United States

USD – US Dollar

WACC - Weighted Average Cost of Capital

WTO – World Trade Organisation

List of figures

List of tables

Chapter 1. Introduction

When describing business opportunity within the waste management field, Hlousek and McVeigh (2020 p.1) cited the proverb: "*One man's trash is another man's treasure*". If only waste management were that simple. This thesis describes the outcomes of a doctoral research project undertaken between 2020 and 2023 as a portfolio of publications at The University of Adelaide, which advances understanding of how to promote construction and demolition waste management practices through incentives towards the proverb's ideal. A seminal report by the United Nations Environment Programme (2015) noted that production of waste by modern societies is exceeding capacity to recover, process and find a use for the discarded materials. This results in the growth of landfilling practices around the world. Pickin, Wardle et al. (2022) and Masud, Mourshed et al. (2023) reported that waste being disposed to landfill had been increasing, as a trend, since the 19th century. Kumari and Raghubanshi (2023) revealed that as many as 1.3 billion tonnes of unrecovered waste was generated in 2012, reaching approximately 2.2 billion tonnes by 2025.

For the purposes of this thesis and the portfolio publications that form part of it (included from Chapter 5 to Chapter 9), the definition of waste is limited to solid waste. As Maalouf and Mavropoulos (2023) reported, there is also a concept known as trade waste, which is waste arising from the production of exported products that is managed in the country where production takes place. This is important because it suggests countries and firms take responsibility for the waste they produce, whether for domestic or export markets. Powell, Chertow et al. (2018) noted that countries accounting for over 85% of global waste generation have included plans to increase management activities.

Table 1 provides a Summary of Nationally Determined Contributions (NDC) to the Paris Agreement of selected countries in Asia & the Pacific, which are based on the aggregate of waste produced in the countries and are not adjusted for trade waste.

Table 1 - Summary of NDCs of selected countries in Asia & the Pacific and contribution of waste

Country	2030 Target	Base year	Base year emissions		
			Total (tCO_2e)	Waste (tCO_2e)	Waste (%)
Australia	43% reduction in total absolute emissions by 2030	2005	608,650,000	14,280,000	2.35%
China	60-65% reduction in emissions intensity per unit GDP by 2030	2005	7,250,000,000	127,000,000	1.75%
India	45% reduction in emissions intensity per unit GDP by 2030	2005	1,820,000,000	67,800,000	3.73%
Indonesia	29% (unconditional) and 41% (conditional) reduction on business as usual	2005	628,000,000	93,800,000	14.94%
Japan	46% reduction in total absolute emissions by 2030	2013	1,340,000,000	22,530,000	1.68%
Malaysia	45% reduction in 2005 absolute emissions by 2030.	2005	252,000,000	21,900,000	8.69%
New Zealand	50% reduction in 2005 absolute emissions by 2030.	2005	57,240,000	4,380,000	7.65%
Philippines	Peak in absolute emissions by 2030. 75% reduction, 2.5% of which is unconditional.	2005	159,000,000	16,400,000	10.31%
Singapore	Reach an absolute target of 60mt of emissions by 2030.	2005	36,300,000	338,000	0.93%
South Korea	40% reduction on absolute emissions by 2030 from 2018 base year.	2018	739,000,000	19,200,000	2.60%
Thailand	Unconditional 30% reduction against business as usual and conditional 40%.	2005	350,000,000	19,400,000	5.54%
Vietnam	Unconditional 16% reduction on business as usual and unconditional 44%.	2005	217,000,000	12,400,000	5.71%

Source: NDC Registry (https://unfccc.int/NDCREG accessed on 13 June 2023)

There are several reasons why waste is of concern to society. The United Nations Environment Programme (2015) identified damage to the environment and harm being caused to human health as areas of impact that directly arise due to landfilling of waste. In other words, waste is a source of negative social externality; In other words, this is the uncompensated harm suffered by persons and groups of people as a result of production and consumption activities carried out by others. Economists have often described conditions that give rise to externalities as being *market failures* (Sandmo 2000, Stavins 2003, Helbling 2020). Other problems also arise, such as inefficient resource allocation, information asymmetry, insufficient supply of public goods, monopoly or imperfect competition and ill-defined property rights (Coase 1988, Zou 2024). These concepts are considered in more detail throughout this thesis.

Scholars and analysts, such as the Ellen MacArthur Foundation (2019) and Marín-Beltrán, Demaria et al. (2022) have also identified the substantial economic and financial costs to businesses and households resulting from waste. Consumers pay for goods and materials; and the component of those goods and materials that is eventually discarded and/or landfilled is not put to any productive use. While these losses are of concern to overall productivity of an economy, they are also a private concern for firms and households. Just because a person is wasting resources, in and of itself, does not mean it is wrong in and of itself. However, where the practice generates externalities, it implicates others and leads to inefficient outcomes for society.

The construction and demolition waste sector is one of the largest contributors to unrecovered solid waste, making up about 40% of the global total (Peng, Lu et al. 2022). Several studies have identified that such waste arises in different stages within the construction cycle, encompassing pre-construction activities and the manufacture of key materials that are used in construction like steel, cement, aluminium and plasterboard (Ginga, Ongpeng et al. 2020, López Ruiz, Roca Ramón et al. 2020). While some efforts are being made globally to recover construction and demolition waste and either reuse or recycle discarded materials (Mahpour 2018, Benachio, Freitas et al. 2020), there is still a long way to go before all of the trash becomes treasure for others. Until such time, the resulting externalities remain a challenge for society.

Steel is a commonly used and critical construction material. In a country like Australia during 2022, steel contributed over AUD 12.2 billion within over 1,000 companies in the construction industry and the sector employs just over 18,000 people (IBIS World 2023). Its environmental impacts are well understood with several authors noting that its production is responsible for between 7-9% of global greenhouse gas emissions and is generally considered a hard-to-abate industrial sector (Söderholm and Ekvall 2019, Liang, Wang et al. 2020). Others such as Cooper, Ryan et al. (2020), Pandit, Watson et al. (2020), Hites (2020) and Gamage, Ramirez et al. (2023) noted that progress has been made in recovering and recycling waste steel, which is yielding environmental benefits. Notwithstanding, the absence of fully developed markets and incentives to encourage greener steel are cited in other studies as a barrier to further progress (Muslemani, Liang et al. 2021).

The need for incentives to encourage more resource recovery and recycling in the construction and demolition waste sector – sometimes referred to as circular business practice - has been identified as important by several authors (Calvo, Varela-Candamio et al. 2014, Hu, Peng et al. 2019, Shooshtarian, Caldera et al. 2022). Several incentive systems have been identified in these studies, including voluntary initiatives, direct regulation, taxes (levies), subsidies, case law precedents and market-based incentives. However, there is no consensus yet on the most efficient approach (Peng, Lu et al. 2022).

The Ellen MacArthur Foundation (2019), a prominent non-governmental organisation, noted that circular practices in waste management are consistent with those needed to mitigate the risks of climate change. Grubb, Jordan et al. (2022) and Eskander and Fankhauser (2023) found that climate policies and legislation like emissions trading had provided positive incentives for reducing emissions and recovering waste, though noted that some materials may be at risk of carbon leakage in some cases when countries have differing policies.

Carbon leakage occurs when greenhouse-gas intensive production relocates to jurisdictions with less stringent or no emissions constraint. Keen, Parry et al. (2022), Meyer and Tucker (2022) and Leonelli (2022b) noted the development of new incentive mechanisms to manage carbon leakage in trade-exposed, emissions intensive construction material production sectors like steel, cement and aluminium, known as border carbon mechanisms. Rossetto (2023a) examined a proposal for a border carbon mechanism in the European Union and concluded that, if coupled with removal of freely allocated emissions permits, would lead to an incentive that could accelerate steel recycling.

This raises a question about the nature of incentives within the construction and demolition waste ecosystem, as well as what, if anything, should be done to increase societal welfare. According to the Concise Oxford Dictionary of Current English (1976 p.176), an incentive is "*a thing that motivates or encourages someone to do something*". Mathis (2009) summarised the work of classical economist Adam Smith, outlining four main drivers that act as an incentive for private actors, which are sympathy and the ethical notion of an impartial spectator, social and ethical norms, laws and regulations and the forces of competition.

These observations provide counterpoints to important economic theories relevant to the study of incentives. First is Coase's Theory, which is concerned with the use of property rights-based mechanisms to incentivise compensation for market failure. It states that the costs of addressing the market failure will be the same regardless of how property rights are initially allocated, if one assumes that there are no transaction costs (Coase 1960, Calabresi 1968, Calabresi 1991). If Coase's Theory were entirely valid, how would one explain the observation by Rossetto (2023a) that free allocation of emissions permits impacts the incentive to recover and utilise more scrap steel? Alternatively, are the administrative costs associated with managing the allocations of permits sufficiently connected to the process that they be regarded as transaction costs? The second is Porter's Hypothesis, which states that higher environmental standards drive innovation and enhanced competitiveness (Porter 1990, Porter and Linde 1995). If this were universally true, how would it impact understanding of carbon leakage risks which imply a loss of competitiveness? Additionally, is the Porter Hypothesis applicable if once considers the differences in environmental regulations as well as regulatory oversight across international borders instead of adopting a limited and simplistic assumption of uniform exposure of all firms to the same set of regulations. Finally, there is Market-Based Management (MBM), which agrees in principle that the forces of competition drive innovation. Accordingly, this research provides an opportunity to carry out both a *deductive research* to determine the applicability of existing theories as well as *inductive research* to develop new theories (Armat, Assarroudi et al. 2018, Woiceshyn and Daellenbach 2018). These are further explored in the Literature Review (Section 2.6) and Discussion (Chapter 10).

1.1 Gap in the knowledge

There is a gap in the knowledge of what can be done to best incentivise improvements, by private actors, in waste management practices. It leads to a fundamental question: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* This therefore became the research question for this research, focused on the specific case of steel. The limitation in scope is done to align with the requirements of a doctoral research project, though the findings are relevant to several other materials within construction and demolition waste management, such as aluminium, cement and plasterboard. In that context and to answer the research question, five research objectives were also developed as follows:

Objective 1. Define the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation (levies) and market-measures, that be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices.

Objective 2. Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste.

Objective 3. Examine the long-term feasibility of international measures – in particular border carbon measures – as a means of providing incentives for resource recovery and utilisation in construction and demolition waste practices.

Objective 4. Assess the effectiveness of voluntary action by firms to address externalities generated within the construction and demolition waste ecosystem.

Objective 5. Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management.

In addressing these objectives, the research makes a significant contribution to the advancement knowledge in not only the construction and demolition waste field, but also that of welfare economics, climate policy - applied to international trade and the transition of heavy industry - and the purpose of corporations.

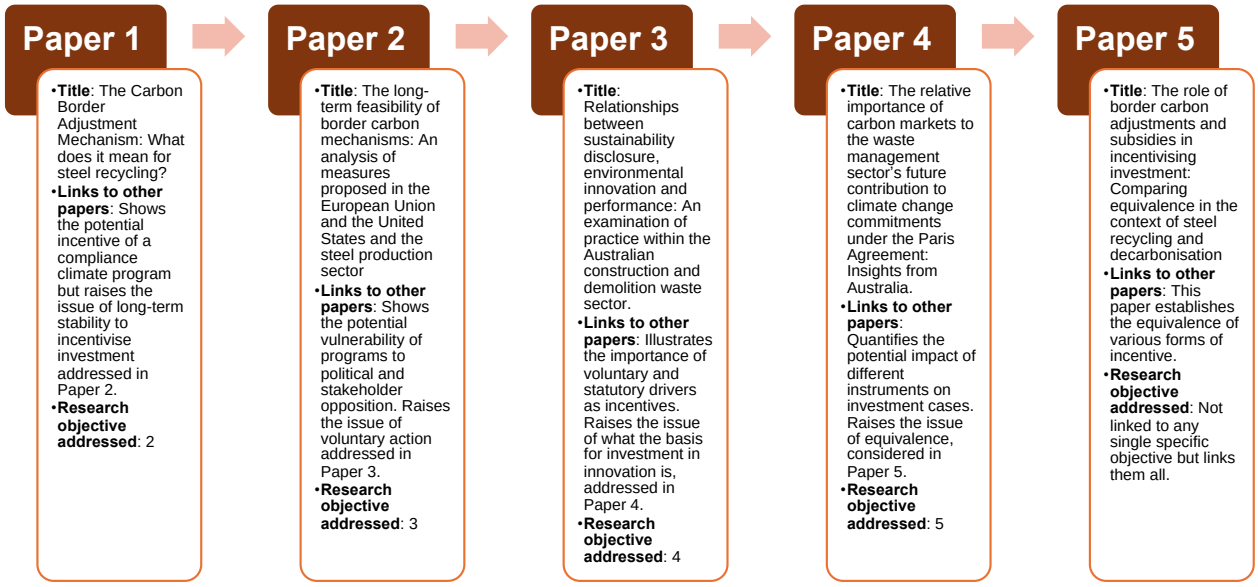
1.2 Background

The research presented in this thesis addresses the growing need for incentives to change the behaviour of private actors in the construction and demolition waste sector and encourage greater levels of resource recovery and utilisation. It comes at a time when three macro-trends are influencing the field. First, that there is an increasing understanding both in practice and among policy-makers that there are synergies between climate change and waste policies. Cutting emissions has potential encourage greater levels of resource recovery - and vice versa.

Secondly, that countries' and regions' are beginning to introduce environmental constraints into international trade regulation. A new type of instrument known as a *border carbon adjustment*, which is designed to create a level playing field across commodities produced in different jurisdictions, is becoming a significant factor affecting both the waste management and resource recovery sectors. Finally, that the attractiveness for subsidisation as a means of transitioning industry to more sustainable practices is increasing. At the same time, relatively little is known within the scholarly domain about the efficiency of different approaches and the extent to which interventions in the market are needed to augment voluntary action.

Accordingly, this thesis was prepared as a portfolio of journal publications that aimed at addressing the need for improved understanding of how these macro-trends can affect practice, what the theoretical implications are and what policy makers can, if anything, consider in response. Figure 1 below summarises the relationship between the five papers, illustrating each one's link to the other papers, the relevance to the macro-trends and the research objectives that each was designed to address.

Figure 1 – Relationship between the portfolio papers in this thesis



While some of the examples and cases presented in the papers arise from Australia, the European Union and the United States, the boundary of the research is not limited. Its findings and contributions are global.

1.3 Contribution

This research makes a number of contributions to practice, theory and policy development. In the area of practice, the first portfolio paper shows that climate-orientated action can deliver resource recovery co-benefits. This is relevant due to concerns that over-regulation represented may represent a barrier to more sustainable construction and demolition waste management practice. There are some preconditions around the extent to which co-benefits can be delivered, such as the need to reduce to the maximum extent possible free allocation of emissions allowances. By leveraging climate action, managers will be able to focus activities to achieve the most efficient outcomes. Policy makers will be able to rationalise the number of endeavours that will lead to less regulatory burden for enterprises whose activities they seek to influence.

The second portfolio paper illustrates that the sustainability of unilaterally designed international mechanisms – like border carbon mechanisms – are at risk due to their inconsistency with the common but differentiated responsibilities provision of the United Nations Framework Convention on Climate Change (UNFCCC) and perceptions in other countries of sovereign autonomy. It places into frame the tension between the need to remove free allocation of permits in emissions trading systems (which are understood to be limiting incentives to abate) and the problem of carbon leakage. The third portfolio paper highlight the role that voluntary action can play as an incentive, which deepens practical understanding of the boundaries around contemporary concerns over corporate greenwashing.

The fourth portfolio paper contributes to understanding of what constitutes additionality and how it can be assessed, with the insight revealed that a project or investment activity can access two or more incentive mechanisms and still be additional. This can also be a desirable characteristic that would encourage more investment because the diversity of cash flow provides a natural hedge against volatility. The impact of this work also arises in the broader sphere of finance (development finance, climate finance and sustainable finance), where there has been a perception that if a project is accessing carbon markets then it should not be eligible for climate or development finance and vice versa.

In the area of theory, the thesis tested the applicability of the renowned Coase's Theory on social costs. Among the main propositions within Coase's Theory is that social costs (often called externalities) are best internalised through the use of property rights-based systems. Coase also held that, where transaction costs are assumed to be zero, the initial allocation of property rights would make no difference to the social cost or efficiency of the outcome. This first portfolio paper illustrated that, in the context of emissions trading systems, it is material whether or not emissions permits are first allocated to liable entities.

While free allocation occurs generally as a means of reducing the risks of carbon leakage, it is not plausible to state that this can be written off as a transaction cost. Liable entities being in possession of freely allocated rights to emit reduces the incentive to abate. This principle was elaborated in detail within the first portfolio paper. It would suggest further qualifications are needed, as an update to Coase, to the extent that one maintained the theory were valid.

The second portfolio paper illustrated that the Porter Hypothesis (which seeks to explain how environmental regulation can drive innovation by firms), if it held true, ought to invalidate concerns about carbon leakage. Firms, when faced with higher emissions standards, would innovate rather than relocate. This seems to overlook the role that imports have in replacing higher cost production. Indeed, portfolio paper two presented evidence that suggests, over the last 10 years, the European Union has gone from being a net exporter of steel to an importer of growing volume. All of this occurred while emissions constraints became tighter and European carbon prices increased. It is also likely that the Porter Hypothesis is more applicable in national contexts where environmental constraints are uniformly applied. This is not always the case in international contexts, however, where variations in policies can exist.

In the area of policy, the third portfolio paper added clarity for policy-makers on the legitimate but qualified role that voluntary incentives can have on improving outcomes. Where intervention is needed, the fourth portfolio paper provided a detailed definition of the different kinds of economic incentive mechanisms that can be used, from revenue support to cost-of-capital support and negative externality levies. It also identified that interventions that result in the provision of incentives ought to, in principle, result it the most efficient (Pareto or Kaldor-Hicks) outcome. This would imply that those harmed by negative externalities or those producing positive externalities are compensated as directly as possible.

1.4 Limitation of the research

The research outlined in this thesis is subject to the following limitations:

i. There are many different materials used in construction and equally different feedstocks used in their production. In order to focus the research, it considers steel in great detail. While steel is an important construction material and worthy of detailed consideration, it there are potential differences with others like aluminium, plasterboard, cement, among others, which this research does not cover.

ii. It is focused on economic incentives as the motivators for change. There are other kinds of incentives, which include regulatory actions to prohibit certain actions or to mandate others, as well as other factors that affect decision-making such as ethics. These are outside the scope of this research project and therefore serve as an important limitation.

iii. It does not analyse the forces that bring about the incentives via public intervention in markets, which might be explained using theories of the political economy and public choice.

Chapter 2. Literature review

The purpose of this chapter is to present the findings of the literature review. The research project was built upon research across several themes emerging both in practice and in scholarly endeavour, including construction and demolition waste, resource recovery and utilisation practices linked to the circular economy, steel production and innovation, welfare economics and the analysis of social cost and understanding applications of the theoretical frameworks contained in the work of Coase and Porter. The following chapter therefore summarises the state of the art in each of the aforementioned areas.

The literature review was commenced in 2020 and was continuous updated during that period before being completed in 2023. Literature was identified initially using keywords like “construction and demolition waste”, “steel”, “incentives”, “circular economy”, “resource recovery” and ”embodied energy”, as well as combinations of these terms. After initial rounds, it became clear that other disciplines were relevant to the research so additional terms were added such as “market-based mechanisms”, “efficiency”, “externalities”, “industrial organisation” and “welfare”. Relevant publications were identified using a variety of scholarly databases and sources such as Google Scholar and Scopus, which are reputable databases for academic literature connected to the field.

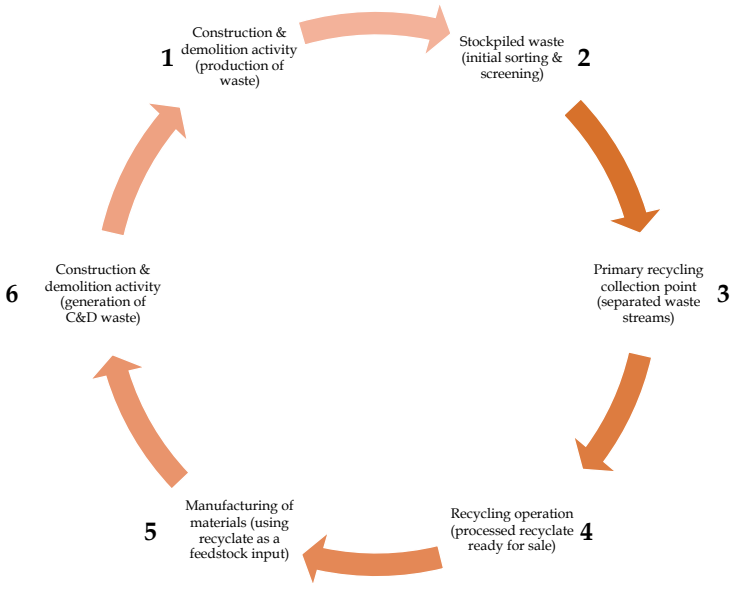
Given the links between this research area and the industry, trade and practice sources such as financial market media, research reports and public agency - both government and multilateral institutions publications – were also considered. Literature was coded for its relevance to several sub-categories, which were “construction and demolition waste”, “steel”, “calculating social costs and benefits”, “methods of intervention”, “financial incentives” and “applicable theories”. These coded areas have been used as the sub-headings in the sections to follow. In addition to this chapter, each of the portfolio papers contains its own literature review. Consequently, this chapter complements literature reviewed in each portfolio paper.

2.1 Construction and demolition waste

Construction and demolition waste arises in different stages of the construction cycle, from pre-construction activities and the manufacture of key materials that are used in construction like steel, cement, aluminium and plasterboard, to construction activities themselves and end-of-life treatment of structures and their constituent materials (Ginga, Ongpeng et al. 2020, López Ruiz, Roca Ramón et al. 2020, Mhatre, Gedam et al. 2023, Nawaz, Chen et al. 2023). Purchase, Al Zulayq et al. (2021) claimed there has been a prevailing perception of zero value, and construction and demolition waste is unwanted and problematic, capable of causing harm to both the environment and to human health. Iodice, Garbarino et al. (2021) and Magrini, Dal Pozzo et al. (2022) published research underscoring environmental and health impacts of construction and demolition waste management practices.

Construction and demolition waste management practice is, in effect, like an industrial ecosystem, consisting of a network of suppliers, processers and end-users of the various inputs and outputs. Figure 2, below, is a diagrammatic representation of the generic industrial ecosystem for construction and demolition waste, which has been adapted from the Australian National Waste Report 2022 (Pickin, Wardle et al. 2022).

Figure 2 - Representation of the construction and demolition waste management ecosystem



Source: Adapted from Pickin, Wardle et al. (2022) National Waste Report 2022

While definitions of construction and demolition waste in legislation are reflective of the aforementioned zero value understanding, Papastamoulis, London et al. (2021) noted that scholarly attention within the field is moving towards it being an input for other material development processes; part of the circular economy (refer Section 2.1.9 for more detail on this link). Resource recovery and utilisation is receiving an increasing amount of scholarly attention, particularly within the broader area of the circular economy. There is also a growing amount of practice literature emerging. It is not limited to construction and demolition waste, with resource recovery and utilisation industries servicing a number of sectors across the economy. Liang, Liu et al. (2021) and Prasad, Sakura et al. (2022) noted that resource recovery and utilisation across all sectors - and not limited to construction and demolition waste - forms part of a circular hierarchy. This hierarchy prioritises waste elimination through design and reuse above recycling and material resource recovery, with composting, energy recovery and landfill the last stages in the hierarchy.

2.1.1 Industrial organisation

Industrial organisation is "…*a field of economics dealing with the strategic behaviour of firms, regulatory policy, antitrust policy and market competition. Industrial organization applies the economic theory of price to industries. Economists and other academics who study industrial organization seek to increase understanding of the methods by which industries operate, improve industries' contributions to economic welfare and improve government policy in relation to these industries*" (Chen 2020 p.1). A number of studies over the last few years have identified that there are different organisations operating in these different stages of the construction and demolition waste ecosystem shown in Figure 2 (Caldera, Ryley et al. 2020, Newaz, Davis et al. 2020). In other words, there appears to be a disaggregation of the eco-system with smaller markets emerging according to different functional areas (Rossetto 2023b).

Rather than construction firms creating vertically integrated business models capable of delivering on all six of the mentioned stages, it is common to observe different firms participating in the same value chain. In fact, it is notably similar to the way in which the broader and modern construction industry has separated itself into disaggregated supply chains consisting of separate legal entities under separate ownership and control rather than have larger and more vertically integrated firms (London and Kenley 2001, Doree 2004, London, Formoso et al. 2008).

Another important feature of the construction and demolition waste eco-system's industrial organisation in a country like Australia is the prevalence of government-owned business enterprises. According to the Australian Bureau of Statistics (2013) there were 547 General Government businesses operating in the waste management and recycling sector across the six states and two territories of Australia, compared to 2,120 private trading businesses (noting that some of the private businesses include those with publicly traded shares; and that the total number may be less as some businesses operate in multiple states and territories, so therefore could be counted twice).

This means that the concentration of government-owned business enterprises within the total eco-system for waste management, in general, is at least 20%, which is significantly greater than in other sectors of the Australian economy. In some states, such as Western Australia, the share is closer to 40% implying stronger emphasis on state-ownership (Australian Bureau of Statistics 2013). Despite this, Rossetto (2023b) illustrated the industry was highly concentrated with several large, privately owned firms contributing to much of the annual turnover.

Few studies have been undertaken to explain why there is such a high percentage of government control and ownership in the waste management sector, though there are some indications from a broader economic perspective. Australia has had a long tradition of state-owned enterprises operating in key sectors, which came into focus during the late 1980s due to the development of competition policy. According to the former Economic Planning Advisory Council, cited by Marsden (1998 p.4), "….*Australian governments have chosen to produce goods and services through public enterprises to facilitate the control of natural monopolies, 'safeguard' competition in some regulated industries, promote longer term views of investment needs and opportunities, facilitating the pursuit of social objectives*".

This illustrates that social objectives are an important point of justification. It also implies that, in some sectors, the appetite for risk among the private sector to make investments into infrastructure needed to provide essential services may not be sufficient to induce the private sector into these industries.

Finally, there is a suggestion that state ownership can also be justified as an alternative to regulation. It is noteworthy that there are some instances in Australia in which there are government-owned business enterprises competing against privately owned businesses (with electricity generation being an example). For this reason, competition policy in Australia introduced the notion of competitive neutrality to provide guidelines for how they should operate in situations where they competed with private interests (Cully, Bakhtiari et al. 2015).

This is quite important as government-owned business enterprises may have different bases for decision making compared to private industry, as well as lower cost base (Hanrahan 2021). For example, cost of capital for a government-owned business enterprise is likely to be lower than for a small to medium enterprise, or that the need to generate financial returns is lower, meaning that investments may not always need to be as profitable to secure a return on investment. There are some occasions in which a government-owned business enterprise may not need to make a profit at all. In the waste management sector, some government business enterprises originate from the local government sector, which some authors have noted is a consequence of the historical role councils played in kerbside waste collection and landfill operation (Rossetto 2023b).

It is also notable that Australia is pursuing a broader strategy of *reshoring* of some waste management and processing services by taking initiatives to phase out the export – via eventual prohibition - of certain waste categories such as paper, plastics, rubber tyres and glass (Council of Australian Governments 2020, Green Industries South Australia 2020). Reshoring is a term being used for the process of repatriating manufacturing into a country (Rojas, Routh et al. 2022).

Reshoring is part of a broader trend in public policy, where governments now seek to diversify away from supply chains - for specific products and materials of strategic value – that originate from companies and countries perceived as being more prone to external shock (Rojas, Routh et al. 2022). It is yet to be seen in Australia whether there is capacity among the private sector to handle the nearly 650,000 tonnes of waste per annum previously being exported that will now need to be processed domestically from the four waste streams aforementioned (Council of Australian Governments 2020).

It is also worthy of note that, in parallel to this, there are industry bodies – with largely private sector membership - in other sectors of the Australian economy currently calling for extensions of such waste export prohibitions (noting that the current export prohibitions only cover 650,000 tonnes of the 4.5 million tonnes of waste exported from Australia per annum) for the reason that they are currently unable to compete with export demand. In other words, the private sector wishes to make greater use of waste but seeks government support to prohibit certain customers for that waste – from abroad – from competing to procure that waste commercially.

Notwithstanding the above, noting some of the differences in business decision making parameters, such as those outlined by Hanrahan (2021), there may indeed be a significant ongoing role for government-owned business enterprises in the construction and demolition waste eco-system. This may act as a safeguard against waste not being processed locally and where it needs to be landfilled. These elements of industrial organisation – from the disaggregated nature of the industrial eco-system to the higher than normal concentration of state ownership of the businesses operating within that eco-system - make the construction and demolition waste management sector interesting for further analysis in the context of this research.

2.1.2 Markets and marketplaces

Connected to the issues identified about industrial organisation is the question of whether markets exist in the construction and demolition waste eco-system. Researchers have noted that markets are important enablers of private capital allocation (Samuelson 1958, Sandmo 2000, Brown 2018). If markets are effective, they ought to allow price discovery (that is, for firms on the supply and demand sides of the production cost curves of specific products and services to interact and discover what is the optimum price for those products and services), the development of risk management instruments and the revealing of incentives that facilitate investment. In construction contexts, this might include a range of financial instruments such as commodity derivatives and financing methods such as supply chain finance.

The existence of competition and choice for producers and consumers allows for bargaining and the capacity for negotiation, leading to value creation. It is important, if we are to assess them adequately, to establish what the main characteristics of markets are. This is not a precise science. The most comprehensive understanding of markets arise from disciplines outside construction and demolition waste, such as economics and law (Coase 1988, Stavins 2003, Deryugina, Moore et al. 2021). The study of markets belongs to the general discipline of micro-economics. According to the economist Robinson (2017 p.1), a market is "…*a means by which the exchange of goods and services takes place as a result of buyers and sellers being in contact with one another, either directly or through mediating agents or institutions*". The author makes reference to classical economists, such as Marshall (2013), stating that marketplaces do not need to be in a specific location and can represent broader geographical areas where prices for specific goods and services tend towards equality over time.

Among other key characteristics are the existence of a first producer and a final consumer, between which intermediaries may also exist, as well as common approaches to specification of the goods and services being bought and sold. Authors within the legal discipline add additional detail, noting that a marketplace may also feature the potential for demand and supply substitution. This means that a consumer has a choice of any number of potential supplies for goods and services; and a supplier ought to have the ability to find any number of alternative customers (Baker 2007, Ferro 2019, Australian Competition and Consumer Commission 2020).

This additional definition is due to the importance of these factors in the assessment of market abuse within competition and consumer protection law, however it also has the effect of broadening the scope for price discovery and value by market participants. The more opportunities there are to purchase or sell a given product or service, the more scope there is to negotiate terms and conditions among the participants.

Applying these definitions to construction and demolition waste management is useful for determining whether activities are or could genuinely be market-based. To be so, the product or service should be available from several suppliers; and the consumer should have the ability to source it from multiple potential suppliers. It also ought to be possible to clearly specify the product or service. Given that recent studies within the construction and demolition waste discipline have not explicitly used or applied these definitions, they could in future be deployed as boundary conditions for further research (Salman, Savindi et al. 2020, Shooshtarian, Maqsood et al. 2020). Recent research by Caldera, Ryley et al. (2020) found that which is able to (a) test the interactions between people and technology associated with waste trading and (b) support enhanced understanding as to the business case for construction and demolition waste marketplaces is of importance.

2.1.3 Barriers to resource recovery

Several benefits of resource recovery and utilisation processes have been identified by various scholars around the world, though their realisation is impeded by barriers. In the case of plasterboard, Jiménez Rivero, Sathre et al. (2016) observed that embodied emissions levels fall the higher the recycled content used due to less need for energy intensive procurement of raw materials like gypsum. In Australia, the Clean Energy Finance Corporation and Arup (2021) described resource recovery as delivering triple impact across economic development, employment and lowering greenhouse gas emissions. Thomson (2021) noted resource recovery reduces the amount of potentially toxic materials going to landfill, which has a corresponding positive impact of reducing leachate discharges. Allwood (2014) exercised some caution, however, arguing processing waste material can sometimes consume large amounts of energy; and materials tend to degrade. This means recycled content often cannot be used for the same purpose from which it was recovered.

Construction and demolition waste, notwithstanding, remains a problem. It continues to account for around 40% of waste sent to landfill globally (Peng, Lu et al. 2022). Scholars have also, therefore, focused some attention on what the barriers are to greater resource recovery and waste minimisation within the sector. Shooshtarian, Caldera et al. (2022) and Mhatre, Gedam et al. (2023) found the existence of too much regulation was a problem, with the latter even noting that infringing safety rules was a barrier to resource recovery.

Wu, Zuo et al. (2023) identified that some operators may even be willing to export construction and demolition waste across borders if there were economic advantages in doing so. If the landfill charges in another jurisdiction were lower, this could act as an incentive not to recovery resources from waste material but rather to export it to the jurisdiction with lower costs. To illustrate this example, the Clean Energy Finance Corporation and Arup (2021) produced a summary of the landfill charges that vary across states in Australia. Some states like South Australia and New South Wales were charging significantly more per tonne (above $140/t) in metropolitan areas than regional and metropolitan areas in other adjacent states such as Queensland and Victoria.

Figure 3 - Summary of landfill charges in 2021 across different Australian states

State	Metropolitan	Regional
New South Wales	$146/tonne	$84/tonne
Queensland	$80/tonne	$80/tonne
South Australia	$143/tonne	$71/tonne
Tasmania	$20/tonne	$20/tonne
Victoria	$125/tonne	$110/tonne
Western Australia	$70/tonne	$70/tonne

Source: Rossetto (2023c) based on Clean Energy Finance Corporation and Arup (2021 p.19)

The literature illustrates a range of barriers including information access, economic, technical and regulatory. Su, Peng et al. (2020) found that information asymmetries were an impediment to making greater use of construction and demolition waste, where those in possession of waste are unable to find parties willing to purchase that waste in a timely manner. In general. Mahpour (2018), López Ruiz, Roca Ramón et al. (2020), Ginga, Ongpeng et al. (2020) and Purchase, Al Zulayq et al. (2021) identified high upfront costs and insufficient demand for secondary materials, driven by unachievable acceptance criteria, as being a key impediment.

Kyriakopoulos (2021), the Clean Energy Finance Corporation and Arup (2021) and Hina, Chauhan et al. (2022) identified that resource recovery for the construction and demolition waste sector is capital intensive and there is a lack of existing infrastructure to handle, sort and process incoming waste, which is often contaminated. Prasad, Sakura et al. (2022) found that procurement functions in many businesses are limited in capacity to write specifications that include materials with recycled content. Some of the barriers are similar to those observed in construction and demolition waste research, though a greater emphasis appears to be placed on capital costs and economic viability.

Studies have also investigated what can be done to remove the barriers. Mahpour (2018) advocated the use of public subsidies. Ghaffar, Burman et al. (2020) observed that direct regulation was having an impact but argued for more stringency. López Ruiz, Roca Ramón et al. (2020) and Peng, Lu et al. (2022) identified the need for economic incentives to make circular practices in construction and demolition waste more financially attractive.

Oluleye, Chan et al. (2022) argued that setting better technical criteria for material acceptance was needed. Benachio, Freitas et al. (2020) identified importance in better understanding how businesses in the construction and demolition waste industry adapt to more stringent regulations. Manninen, Koskela et al. (2018), Pieroni, McAloone et al. (2019) and Wasserbaur, Sakao et al. (2022) found there was a need for business model innovation that is capable of attracting the finance needed.

Others, such as Leal Filho, Saari et al. (2019), Salman, Tayyab et al. (2021) and Prasad, Sakura et al. (2022) considered potential for extended producer responsibility schemes, which create a long term liability for producers of the products they sell. The Australian Government (2023) noted the importance to the waste and resource recovery sector of generating revenues from the positive emission reduction externality such projects are able to deliver.

2.1.4 Regulatory frameworks

The formation of markets for construction and demolition waste influences the development of laws and regulations; and vice versa. This is a particularly important interrelationship in the areas of both construction and waste management. While it is possible to consider construction and demolition waste as an industrial efficiency issue (that is, waste being a business input that is not necessarily being utilised in the final product, leading to unnecessary input costs), a significant amount of attention in research terms has been focused on the environmental aspects of waste management practices (Hoornweg, Bhada-Tata et al. 2013, Ghaffar, Burman et al. 2020, Wu, Zuo et al. 2020).

Much of the regulatory action around the world has been focused on command-and-control style measures rather than market-based incentives. Papastamoulis, London et al. (2021) found this to be a consequence of a zero value approach to considering waste. Rossi and Morone (2023) noted this includes prohibiting certain activities or mandating others. Shooshtarian, Caldera et al. (2022) noted that regulations, including those related to environmental law that influence the construction and demolition waste sector, were sometimes overwhelming for practioners. Notwithstanding, reduction of waste going to landfill remains a priority for governments. Rossetto (2023c) provided an overview of the targets to reduce waste of countries throughout the Asia and the Pacific region. The paper forms part of this thesis and can be found in Chapter 8.

In the specific area of environmental law in jurisdictions that also use common law such as the United States and Australia, a proliferation of law has been observed in recent decades (Latham, Schwartz et al. 2011). While this phenomenon is observable, it is also clear that common law – and specifically the law of tort – is influencing rules affecting marketplaces linked to construction and demolition waste management.

A number of interesting conflicts and tensions arise in relation to the impact these sources of law and regulation have on markets. While authorities such as Council of Australian Governments (2007) reason that the purpose of statutory and regulatory approaches should be driven by optimisation of societal welfare, the law of tort is generally a consequence of a dispute between two parties based. Therefore, the basis for the development of this kind of law is the interest of the parties to that dispute, not societal welfare. There are also studies recognising that variations in the application of important risk parameters such as the precautionary principle across these areas impact markets (Read and O'Riordan 2017, Hausken 2021).

Of relevance to this thesis, there have not yet been any published studies that specifically look at the impact that development of both statutory and common law has on the efficiency of markets in waste. It is, therefore, not yet widely known whether these phenomena cause or limit the occurrence of externalities.

2.1.5 Point of intervention

Across the construction and demolition waste management field, there is research that considers both upstream - in material production industries as suppliers to the building industry - and downstream - such specifiers of materials such as clients, contractors, architects and engineers. These issues connect very closely to those associated with industrial organisation within the construction and demolition waste eco-system previously identified. This is because it is fundamental to the efficiency of any new intervention to understand where current inefficiencies lie before new measures capable of improving upon the status quo can be designed.

Broadbent (2016) and Cooper, Ryan et al. (2020), looked at the upstream issues associated with utilising recycled content, being scrap steel, as a feedstock in new steel production; including structural steel for construction. They noted the challenges that exist for designers in obtaining credible information at the product level, along with the commercial constraints that apply to projects.

Gelowitz and McArthur (2018), Illankoon and Lu (2020) and Salman, Savindi et al. (2020) studied downstream issues associated with promoting greater utilisation of materials available in construction and demolition waste streams. It is a feature of these studies that they are limited by considering one-off style solutions, project-based solutions. This is as opposed to upstream interventions that have the potential to generate more sustainable and commoditised solutions. Such solutions may, in due course, become capable of meeting specifications which represent market standard.

The interaction of upstream and downstream factors is, therefore, not particularly well understood in current construction and demolition waste management research. By consequence, there are no studies presently available that allow conclusions to be drawn about which approach – upstream or downstream – or combinations of approaches might lead to the most societally beneficial outcomes. There is also an important interaction between the interventions potentially available and the nature of the existing industrial organisation of the construction and demolition waste eco-system, which is not presently well understood.

2.1.6 Jurisdictional complexity

Challenges associated with solving environmental challenges in construction and demolition waste are compounded by jurisdictional complexity. Even though firms operating in the sector are often associated with – or domiciled in - specific regions and countries, it is common that they and their operations expand well beyond the political boundaries of the state in which their headquarters are domiciled or, in the case of a listed firm, its stock is traded. Researchers have, for some time, been interested in the trend towards divergence between the industrial organisation of industry, the geographical locations from which individual firms operate and the political boundaries of these locations (Helm 2011, Alemanno 2013).

In construction and demolition waste management and resource recovery, the phenomenon also applies. Waste generation and disposal practices can span across multiple political and jurisdictional boundaries. It is also reasonably well understood that the main driver of this mobility is the existence of regulatory arbitrages, which can be defined as difference in rules, charges and requirements for waste treatment and disposal from jurisdiction to jurisdiction that can represent materially different costs of compliance for private sector actors (Wu, Zuo et al. 2020, Wu, Zuo et al. 2023).

These phenomena are evident in both scholarly and policy literature (Australian Bureau of Statistics 2013, Kellenberg 2015, Sembiring 2019, Council of Australian Governments 2020, Wu, Zuo et al. 2020). What is less understood in literature is what can and should - if anything - be done to deal with these challenges. The issue has been studied by several scholars in broader environmental disciplines where there are important interactions between markets across these jurisdictional boundaries that impact societal welfare in both jurisdictions, though notably not in the area of waste (Helm 2011, Feaver 2012, Livermore, Glusman et al. 2013).

Actors in different jurisdictions face a choice as to which legal system to contractually specify as the location in which any potential disputes relating to a contract will be settled. An opportunity, therefore, exists to address the issue of interjurisdictional complexity, specifically in the context of construction and demolition waste.

2.1.7 Decision-making and the assumption of rational behaviour

The basis of decision-making in construction and demolition waste and resource recovery markets is an important consideration. There is a temptation to conclude that, provided there are appropriate measures undertaken to internalise the costs of the market failures or externalities, rational behaviour will become the predominant influence on capital allocation and production decisions (noting that some of the important issues identified in industrial organisation suggest that a range of other sub-considerations then become relevant - such as competition, price discovery, transaction costs, risk and the availability of means to manage risk – in the real world).

Given the historically high concentration of state-ownership within the construction and demolition waste (Thomson 2021), the basis of decision-making may not always be commercial and can be influenced by other factors including political considerations (Organisation for Economic Cooperation and Development 1998, Ishak, Ilmar et al. 2021). Some scholarly studies suggest culture - and information asymmetry - are equally important. Studies extend into the specific domain of engineering and construction (Coulson-Thomas 2014, Lines, Sullivan et al. 2015, Cleveland, Rojas-Méndez et al. 2016).

It is therefore both an opportunity and a caution for any future research into construction and demolition waste management to take these factors into account, applying equally to analysis and design of the policies specifically designed to encourage different construction and demolition waste management practices.

2.1.8 Unintended consequences

Not every policy intervention in construction and demolition waste achieves its intended purpose (Muslemani, Liang et al. 2021). Markets and policies designed to encourage market development can sometimes cause unintended consequences. An example is the scrap steel markets that support the development and manufacture of new steel with recycled content. As has been identified by a range of authors, including Broadbent (2016) and Cooper, Ryan et al. (2020), scrap steel markets may inadvertently give a signal that encourages illegal – and even criminal – behaviour. This arises because individuals understand that, due to the liquidity in scrap metal and steel markets, items like cars or building materials can easily be converted to cash. So acute has this problem become that jurisdictions such as New South Wales in Australia have introduced laws to prevent payment by scrap metal processing companies of cash to ad hoc suppliers of the feedstock material (Parliament of New South Wales 2016).

There is an opportunity to analyse the potential safeguards against unintended consequences, as they relate specifically to construction and demolition waste management and associated markets, in new research. Doing so would potentially increase the value and utility of the recommendations arising.

2.1.9 Waste management within a circular logic

The *circular economy* has emerged as an expansion in the scope of studies in waste management. The field includes built environment waste. Several researchers have observed that the circular economy is having a correspondingly powerful impact on stakeholder expectations, policy making and corporate behaviour of firms (Blomsma and Brennan 2017, Isenhour 2019).

A number of scholars, however, disagree on the definition of the circular economy as well as how it should be assessed from a quantitative perspective (Geissdoerfer, Savaget et al. 2017, Winans, Kendall et al. 2017, Zink and Geyer 2017, Korhonen, Nuur et al. 2018). The circular economy itself is also nominally included within the broader field of green finance, which has been noted as a similar area in which there is debate over definitions and standards (Rossetto 2015, Rossetto 2017). The circular economy is one of six areas of environmental impact included within the European Union's sustainable finance taxonomy (European Commission 2020). The following paragraphs consider literature over recent years connected to the circular economy and its connection to construction and demolition waste management.

Notwithstanding, the core waste management principles of reduce, re-use and recycle are regularly present, as are new objectives like keeping materials in economic circulation for as long as possible. Allwood (2014) provided an overview of the circular economy concept. The author challenges the potential environmental benefits a circular economy can deliver if implemented alongside continuous and unconstrained growth models; and presents some very important trends in global growth in demand for materials (steel, cement and paper) alongside other graphs plotting the increase in usable space in buildings and environmental indicators such as increases in global concentrations of greenhouse gases in the atmosphere. In conclusion, the paper finds that bulk materials do not cost enough to encourage real circular strategies.

Geissdoerfer, Savaget et al. (2017) analysed literature to determine links between circular economy and sustainability, given the rise of publications and the possible link to a new way of describing sustainability. The authors noted that much of the research is being driven by European and Chinese scholars, largely in response to increasing regulatory focus in those jurisdictions. The jurisdictions from which most research is emerging are among those who import most mineral and primary resources, such as China and the EU, which would affect trade balances and other macro-economic performance indicators.

Kirchherr, Reike et al. (2017) noted the number of disparate definitions of circular economy in scholarly and trade literature as well as legislation. Among the most prevalent definitions are the four 'Rs' (reduce, reuse, recycle and recover), implying connection to waste management and resource recovery. While sustainable development is often a noted driver of circular economy, the interests of future generations appeared in only one of the 114 definitions. This places circular economy definitions at odds with sustainable development, which explicitly seeks to prioritise the needs of future generations, providing some contrasting findings to (Geissdoerfer, Savaget et al. 2017).

Winans, Kendall et al. (2017) looked at applications of the circular economic concept across the world, seeking to identify its benefits and limitations to future growth. At the beginning of the paper, a brief account is provided on the circular economy concept's history, specifically mentioning China's focus in the 1990s due to limits on economic growth brought about by resource availability constraints. The authors explore applications of circular economy across a number of material segments, including metals, plastics, land, agriculture, wood & paper and even water. They highlight the importance of eco-industrial parks as enablers via the connection of businesses within supply chains.

McCarthy, Dellink et al. (2018) considered 24 modelling studies into the macro-economic impacts of moving toward circular economies. The observation is made that a universally accepted definition of circular economy is absent. It notes that 15 of the studies were conducted since 2015, highlighting the novelty and growing relevance of the circular economic concept. Among the conclusions are the findings that circular economies will not lead to economic losses and may even lead to growth, but that there will be distributional impacts associated with allocative transitions. In this case, losses would be suffered by the raw material producing countries, companies and regions. The report notes the substantial uncertainties associated with the input data and assumptions made and their impact on the results.

Jin, Yuan et al. (2019) studied literature published world-wide over almost a decade (2009-18) on the topic of circular construction and demolition waste to identify the most pressing areas where further research is needed. Identified areas were comprehensive evaluation of the performance of waste management from the life cycle assessment perspective, comparisons of construction and demolition waste management practice between developing and developed economies, building the body of knowledge of the circular economy for its proper application in construction and demolition waste management and continuing development of the human factor-related framework in waste management, such as waste diversion climate and culture.

Nußholz, Rasmussen et al. (2020) examined the performance of a specific business in Sweden that re-uses waste materials and re-sells them as building products in windows, concrete and wood cladding. The authors found that there are benefits on windows and wood cladding, though those benefits are quite marginal with concrete. The business itself is creating value for customers and is profitable, though it is noted that the profits are not significant. The paper noted that there are some areas, including the savings in carbon dioxide-equivalent emissions, in which no financial impact to the company is being delivered, despite the creation of the positive social and environmental externalities. The paper also identifies high upfront costs as a barrier to further implementation.

Aboulamer, Soufani et al. (2020) puts forward an interesting view that public equity markets are unable to properly value the intangible assets created by companies when introducing circular economic business models. The authors cite growth in circular economy focused private equity funds as evidence of this. While intangible assets referred to in the paper are environmental and social benefits created by circularity, the authors are somewhat sceptical though that markets can properly value those intangible assets over direct financial metrics. They conclude financial aspects will always play an important role in allocation of funds, so it is important to find a means to monetise the positive impacts made in other areas – akin to positive externalities used in welfare economics.

Centobelli, Cerchione et al. (2020) carried out a review of literature that encompassed how businesses remodel themselves for the circular economy. The paper found that management practices are influenced by contextual factors, such as laws, policies, incentive and tax programs, as much as by opportunities for both value creation in supply chains and value capture with customers. It describes supply chains as consisting of partnerships rather than customers and suppliers. That said, it is reasonably clear that contextual factors are as important as any in driving managerial change in business organisations. It also calls for research into how businesses can transform existing linear businesses into circular ones. This highlights the fact that there are likely to be barriers for businesses in this transition and indeed risks that might not yet be fully manageable without more being done by governments in relation to the contextual factors.

Dewick, Bengtsson et al. (2020) undertook a critique of circular economy as an investment opportunity, highlighting uncertainties linked to the absence of definitions. This creates difficulty for investors and the authors cite a few examples of how coal companies might be engaged in genuine circular activities but be declined for investment due to other qualitative factors. This is an issue for investment funds that cite circular economy as one of their driving investment themes, citing a new fund under the management of BlackRock as one example.

The authors contend there is a high risk of error if industry groups are allowed to continue to establish the definitions and standards calling for regulatory oversight. Failure to do so will lead to higher levels of risk of corporate greenwashing. The authors express a level of distrust in the finance sector as a whole, saying: "*recent historical experience unambiguously demonstrates that governments should be wary of ceding their regulatory obligations to myopic financial institutions that have repeatedly demonstrated that they operate in accordance with alternative conceptions of the social contract*" (Dewick, Bengtsson et al. 2020 p.2). This is quite an extreme perspective, as voluntary action by firms can, in some cases, produce positive results. The role of voluntary action in construction and demolition waste management, in the context of Australia, is covered in paper three, in Chapter 7, of this thesis.

There are ongoing debates over the welfare outcomes of economic practices as originally noted by Leontief (1970) and discussed more recently by Hart, Adams et al. (2019) and Minunno, O'Grady et al. (2020). The social benefits of resource efficiency, in particular, remains a contested concept. This is primarily due to the fact that some countries derive significant wealth and macro-economic benefits from extractive industries. Significant changes in demand for underlying primary resources, as one would typically see promoted in the circular economy, might have correspondingly negative impacts on the welfare of those countries (Heller 1966, Lèbre, Corder et al. 2017, Cunningham, Uffelen et al. 2019, Schmidt, Feth et al. 2019).

For example, a country such as Australia, which is the largest exporter of iron ore used in steel production globally, earned AUD $63 billion equivalent in foreign currency from such trade during the 2016/17 financial year. These earnings assisted Australia’s maintenance of a positive trade balance during that year in turn facilitating convertibility of its currency for use in importing other goods and services (Department of Industry 2018).

This introduces the notion that circular economy implementation can have cross-border impacts that might positively influence the welfare of some, but cause harm to others. This suggests that there is scope to make different conclusions about the contribution of the circular economy to welfare that change depending on where the geographical and political boundaries of assessment are drawn. Notwithstanding, researchers and policy analysts continue to explore the development of new, circular business models and barriers to implementation including lack of access to finance and exposure to risk and commodity price volatility. Others have looked at optimum policy measures to encourage the transition to more circular practices (Aranda-Usón, Pilar et al. 2019, European Commission 2019, Centobelli, Cerchione et al. 2020, Nußholz, Rasmussen et al. 2020).

Other researchers such as Firouzi and Vahdatmanesh (2019), Pellegrino, Costantino et al. (2019) and Pellegrino, Gaudenzi et al. (2020) have looked at the topic of commodity price volatility management techniques for construction companies, without explicitly drawing any relevance to the circular economy. A common commercial solution for hedging commodity price risk in industrial investments, on both inputs and outputs, is known as tolling. This is a practice whereby an industrial operator fixes the prices of feedstock inputs and production outputs for several years, via physical or financially settled commodity derivatives, in order to secure a production profit margin. In financial industry nomenclature, this can sometimes be referred to as locking in a spread. The certainty of this margin – or spread - together with production volumes becomes very important for the debt financiers of these investments, especially where non-recourse financing structures are used such as project finance. Equity investors may have a slightly different appetite for hedging, as very often the reason for investors to purchase shares in certain companies is due to a bullish sentiment and an appetite, therefore, to be exposed to the market risk associated with a given commodity. That said, it is uncommon to finance any venture entirely with equity, so hedging is an important consideration.

Contemporary academic research into tolling agreements has mainly been focused on sectors such as electricity generation and infrastructure (Bartlett 2019, Spodniak and Bertsch 2020), though recent work by authors such as Dong-Hyun, Eul-Bum et al. (2019) has focused on the use of these agreements in industries that produce building products, such as steel. This is an important example as well because there is also a liquid futures market for recycled feedstock, namely scrap steel on the London Metal Exchange (LME). Scrap steel can be used in steel production that uses electric arc furnace technology, allowing melting of scrap; to become a substitute for iron ore and metallurgical coal as would be used in blast furnace technology (Wood, Dundas et al. 2020).

Steel producers are therefore able to use the futures markets, including the exchange platform provided by the LME, to secure the price at which they can purchase volumes of scrap steel. This can be used to hedge the value of an investment, such as an electric arc furnace (London Metal Exchange 2020). Given the large capital investments needed for electric arc furnaces, 15 months could be considered a short forward time horizon.

2.1.10 Gap in the knowledge

Relatively little, if any, research has been undertaken to consider the current or potential use of tolling structures - or other commodity future hedging strategies - linked to investments in the circular economy. To the author's knowledge, this is even less likely to be so with respect to the scrap steel futures market's role in supporting the financing of electric arc furnaces, which is one of the primary means for producing steel with recycled content (World Steel 2012, Broadbent 2016). Scope also exists to consider the suitability of the existing scrap steel futures markets to support financing of the next generation of green steel production, including whether there is any case for intervention by public authorities to provide liquidity over longer time horizons than the existing 15 months of price discovery available over exchange.

Taking this into account, several research gaps that emerge from the latest work on the circular economy. These include studies on financing activities and the use of markets – both in waste itself and in the positive externalities circular economic practices can create - to overcome the noted barriers. There is also a notable shortage of work that considers the macro-economic and distributional impacts of the circular economy, especially ones that compare it to the more traditional resource-based extractive processes at both the international and national level in overall welfare analyses.

2.1.11 Summary

In summary, research is taking place on the barriers to more sustainable construction and demolition waste management, as well as possible solutions to encourage greater resource recovery and less waste going to landfill. There is an absence, however, of consensus on what are the most significant barriers, as well as what solutions are like to be most efficient or effective in that context. This is particularly evident in that markets and marketplaces, both upstream and downstream, are of critical importance, while at the same time there is an increasing focus on regulatory constraint that actors in the building industry face, including statute and common law. It is also clear that impacts are being observed across borders in marketplaces that span different geographical and political jurisdictions, across which the legal, regulatory and other parameters may apply.

Limitations in the understanding and assessment of current practice and future progress at both the firm and organisation level and at the societal level exist; and represent the gap in the knowledge. These represent areas in which research can be focused in order to advance knowledge.

2.2 Focus on steel

Steel is an important material as an input to many industries. It is particularly energy intensive to produce, requires significant natural resource input - like iron ore, metallurgical coal and primary energy resources from a variety of different fuels - and is responsible for producing as much as 7-9% of the world's greenhouse gases (Cunningham, Uffelen et al. 2019, Wood, Dundas et al. 2020, Muslemani, Liang et al. 2021). At the same time, steel is internationally traded; and is a vital part of the economic prosperity of many countries. This includes as a building product as well as a constituent material in other technologies such as cars, ships and renewable energy plants, among other things (Della Vigna, Stavrinou et al. 2021).

As public and consumer awareness of these issues increases, along with the broader societal focus on solving environmental challenges such as climate change, key industry figures such as Gupta (2020) and organisations like World Steel (2012) suggest there is a pressing need to revolutionise the way steel is produced. This has led to the emergence of green steel.

Green steel is an emerging area of relevance to construction and demolition waste management. Discussion is taking place globally on the possible decarbonisation of steel production (Wood, Dundas et al. 2020, Muslemani, Liang et al. 2021), though some authors have identified more recycling of scrap steel as one of the lowest cost ways to reduce greenhouse gas intensity (Broadbent 2016, Della Vigna, Stavrinou et al. 2021, Rossetto 2023a).

2.2.1 Green steel and the construction and demolition waste ecosystem

Green steel is an area strongly connected to waste management. While it is true that a deep discussion is taking place globally on the possible decarbonisation of steel production (Wood, Dundas et al. 2020, Muslemani, Liang et al. 2021), some authors have identified more recycling of scrap steel as one of the lowest cost ways to reduce greenhouse gas intensity (Broadbent 2016, Della Vigna, Stavrinou et al. 2021). Steel is one of the construction materials whose life-cycle ecosystem can engage with other sectors. Steel waste produced in the construction and demolition can be used to manufacture steel used for other purposes, as indeed the recycled feedstock used to make steel for the building industry can come from waste in other sectors.

In the context of Australia, Pickin, Randell et al. (2018) estimated that the amount of steel in construction and demolition waste is just under 40% of the total has been increasing in the last decade, though so too has the recovery rate. This includes steel waste produced on construction sites, at steel fabrication yards before delivery to site and in steel manufacturing facilities. The Australian Bureau of Statistics, however, in its Waste Account publication, revealed that scrap steel comprised almost half the value of the total exports of waste (Australian Bureau of Statistics 2013). This means that, although it might appear at first glance that a high proportion of waste steel in Australia is being recovered, a large proportion of that waste is being exported where its final use – as part of the green steel industrial ecosystem – cannot be accurately verified.

In terms of use, there is relatively little research available to verify how commonly used recycled steel is in today's construction industry. One possible source is the information contained in Environmental Product Declarations (EPD) published for steel products used in construction. These are not mandatory requirements in Australia as yet and nor does every product have one (Appendix B).. This establishes a reasonably strong case to suggest that steel recycling, as part of the processes linked to the delivery of green steel, are an important part of construction and demolition waste management practice and research endeavour.

There are two generally accepted means of producing green steel. The first of these is direct reduction green steel production (refer Section 2.2.3) and the second is green steel through recycling 2.2.4). Each of these is explained in more detail below along with an explanation of how traditional (integrated) steel manufacture takes place (refer Section 2.2.2).

2.2.2 Traditional (integrated) steel manufacturing

The traditional – and the most common – approach to steel manufacture is what is often referred to as integrated steel. In this process, iron ore – largely pelletised – is fed into a Blast Furnace (BF) along with coke, which is a form of metallurgical coal that is pre-treated in an oven to produce molten iron (sometimes referred to as pig iron). Metallurgical or coking coal is quite different from thermal coal, such as anthracite or lignite, which are commonly used as a primary fuel for power generation.

This is quite an important distinction to make. The molten iron is then fed into a Basic Oxygen Furnace (BOF) along with a small amount of scrap steel, which is largely used to control the temperature of the process. The product of this process is crude steel, which is then further refined and cast before fabrication (Wood, Dundas et al. 2020).

Traditional or integrated steel production is an energy intensive process, not just to operate the furnaces but also to mine, transport and prepare both the iron ore and metallurgical coal needed as inputs. The environmental impacts can therefore range from greenhouse gas emissions (in the form of carbon dioxide), as well as particulates from the waste gases, along with eco-system disturbances that occur in the mining and processing of the raw materials like iron ore and metallurgical coal (Della Vigna, Stavrinou et al. 2021).

2.2.3 Direct reduction green steel

Direct reduction steel manufacture is an adaptation of the traditional process; however, it substitutes coking coal by producing direct-reduced iron rather than molten iron. A critical part of this process is the use of a reductant gas, which might either be natural gas (CH_4) or hydrogen. Hydrogen is not yet a widely produced gas – at least not enough for use at industrial scale as it would be for direct reduction steelmaking, though it is understood to be an energy intensive gas to produce. It is therefore understood within the context of green steel that renewable energy sources would be required to ensure that additional greenhouse gas emissions do not result from this kind of steelmaking process. The direct reduced iron is then introduced to an Electric Arc Furnace (EAF), which is mixed again with scrap steel to moderate the reaction temperature (Wood, Dundas et al. 2020).

As with traditional or integrated steel, the product of this process is crude steel, which is then further refined and cast before fabrication. In order for the steel to be considered green, most analysts and scholars find that the electricity source for the electric arc furnace be low emission, such as renewable or gas fired generation with carbon capture and storage (World Steel 2012, Muslemani, Liang et al. 2020, Wood, Dundas et al. 2020, Della Vigna, Stavrinou et al. 2021). It has been noted by a number of scholars, policy makers and experts that direct reduction steelmaking is in its early stages of development. It is also reliant on the availability of low-cost renewable energy sources and the emergence of a hydrogen supply chain (Gupta 2020, Finkel 2021, Muslemani, Liang et al. 2021).

2.2.4 Green steel through recycling

The other means by which the resource and energy inputs of steel production can be substantially reduced is through the increased recycling of steel and its use in electric arc furnace technology (Della Vigna, Stavrinou et al. 2021). The recovery of scrap metal and its subsequent re-use in steel production is an example of what many analysts, including the Ellen MacArthur Ellen MacArthur Foundation (2019) and Blomsma and Brennan (2017), among others, refer to as a circular economy. This is an economy in which materials are maintained in circulation for longer and longer periods, where waste is reduced by recovering resources and re-using them in industrial and other productive processes. In order to prepare the scrap steel for use in these processes, it is necessary to collect and sort it from industrial and commercial (including automotive) or construction and demolition sources, then crush, shred and separate it and finally melt and purify the scrap (Giurco, Littleboy et al. 2014, Yellishetty and Mudd 2014).

While this is a cumbersome series of steps, it is noteworthy that scrap steel has emerged, notwithstanding, as an internationally traded commodity (London Metal Exchange 2020). Having said that, Yellishetty and Mudd (2014) identified that not all scrap can be used and for every tonne of steel production, roughly 1.1 tonnes of scrap steel are needed. This suggests that some of the 10% of the scrap steel is wasted.

Authors such as Ma, Wen et al. (2014), Della Vigna, Stavrinou et al. (2021), Broadbent (2016) and Cooper, Ryan et al. (2020) specifically looked at the status of and potential for recycling steel in countries such as the United States and China. There is likely potential to double the production of steel using Electric Arc Furnace technology and scrap metal as a feed stock by 2050 around the world. The practice faces several limits, which include – but are not limited to – contamination within the scrap metal feed stocks, the fact that a large percentage of existing steel production uses Blast Furnace and Basic Oxygen Furnace technology – that is, the traditional or integrated steel production process is used - and would require major capital investment to upgrade to electric arc furnace technology.

Pickin, Randell et al. (2018) estimated that the amount of steel – which is the material of focus for this research – contained within construction and demolition waste is just under 40% of the total. This includes steel waste produced on construction sites, at steel fabrication yards before delivery to site and in steel manufacturing facilities. The Australian Bureau of Statistics (2013) revealed that scrap steel comprised almost half the value of the total exports of waste. This means that, although it might appear at first glance that a high proportion of waste steel is being recovered, material proportions of that waste is being exported where its final use cannot be accurately verified at this point.

2.2.5 Economics of the various options

The relative economics and commercial viability of the different choices available for producing both traditional and green steel are of critical importance. Investment analysts have estimated an average cost to de-carbonise steel of around USD $100/t in 2030 and the same again by 2040. Some technologies needed to give effect to such decarbonisation are not yet commercially available, hence there is a degree of uncertainty around these estimates. This issue is exacerbated when one considers that the sources of energy used for steel production (including electricity use which in most cases would be indirect or scope two emissions), which have their own abatement challenges and costs, are likely to increase in importance for those assessing the overall decarbonisation efforts of the sector (Della Vigna, Stavrinou et al. 2021).

While it is not yet a clear pathway for producers to recover any extra costs associated with production, steel has in some regions been the subject of efforts to reduce greenhouse gas emissions that are both mandatory and voluntary. On mandatory efforts, steelmaking has been included within the basic coverage models used in several greenhouse gas cap-and-trade programs such as the European Union's emissions trading system (EU ETS) and the former Australian carbon pricing system that was including under the Clean Energy Act 2001, which was eventually repealed in July of 2014. One of the key sensitivities for including steel in such programs is that the markets for steel in these countries and regions – being the EU and Australia – include steel produced domestically as well as that which is produced abroad and imported. Steel produced domestically, when facing an emissions constraint that increases the costs of production, may not be able to pass on these costs to consumers. The reason for this is that some of the steel imported into the market, which is available for purchase by the same customers as the domestic steel, may not face the same constraints or production costs. Therefore, any attempt by the domestic producers to increase prices to consumers as a means of recovering cost, would result in those producers being less competitive and therefore risk losing market share (Schmidt, Helme et al. 2008, Feaver 2012).

Domestic producers - if left completely to the forces of self-interest and without any other regulated or market-based effort to equalise this cost pressure - would face an incentive to either (a) relocate production to locations without carbon constraints, or (b) produce less steel and allow for more imported steel to be derived from those external jurisdictions without commensurate constraints. This concept has become known as industries at risk of carbon leakage in the European Union, or emissions intensive, trade exposed industry in Australia. What is of note is that this phenomenon would equally apply to industry players that seek to increase the green attributes associated with their production on a voluntary basis, unless there were a demonstrable appetite in the marketplace to pay a premium price for such green steel.

The impact of pricing on steel consumption across an economy has been studied in some detail over the years. Authors such as Crompton (2015) examined the impact of income elasticity on steel consumption across Organisation for Economic Cooperation and Development (OECD) countries. Crompton found that incomes do have an impact on consumption to varying degrees. Where income elasticities are at or below one, the impact is relatively minor. However, where the income elasticity increases above one, increases or decreases in overall income can impact demand for steel.

At least some of the average costs associated with steel decarbonisation can be absorbed by the market in countries with low-income elasticity levels without having a tremendous impact on demand. However, if international trade in steel is not eventually regulated for carbon intensity, it is possible that steel producers that move more rapidly towards decarbonisation will place themselves at a competitive disadvantage compared to producers in other jurisdictions. This is an issue that is well documented internationally (for example in Europe, it is referred to as industries at risk of carbon leakage, whereas in Australia it is referred to as emissions intensive and trade exposed industries) albeit the optimal policy solution has not yet been identified (Grubb, Jordan et al. 2022, Eskander and Fankhauser 2023).

In order to deal with these kinds of competitive distortions from differences in cross-border approaches, scholars and policymakers alike have sought to identify a number of solutions. Some of the earliest efforts included the sectoral agreements, whereby the entire global industrial supply chain for industries such as steel could be captured and regulated for greenhouse gas emissions not by the nation-state or region but by a multilateral enforcement body (Ellis, Baron et al. 2009, Wooders, Cook et al. 2009, Rossetto 2023d).

Based on the impracticalities associated with this kind of approach, regions such as the European Union developed a system of granting free allocations for emissions certificates so that domestic producers could be included in an emissions trading program, but not face a cash cost to acquire some or all the certificates needed. Other proposals, which have become more prevalent in recent years, as evidence by via policy proposals in the European Union and Canada, are the border carbon mechanisms (Rossetto 2023d).

Noteworthy is that the United States and the European Union, on 31 October 2021, made a joint statement on trade in steel and aluminium. This program has been described as a sectoral agreement to deal with emissions intensity of steel production and may include cooperation on carbon border adjustment mechanisms to regulate imports of steel (White House 2021). This announcement permeated the formal talks at 26th conference of the parties to the UNFCCC scheduled for conclusion on Friday 12 November 2021. At least some steel will need to be produced with carbon capture, utilisation and storage by as soon as 2030 (Della Vigna, Stavrinou et al. 2021).

2.2.6 Summary

Steel is an important material used in construction and exhibits potential for becoming more circular and, in doing so, lead to reductions in environmental impacts (Nußholz, Çetin et al. 2023). While green steel manufactured with EAF technology already represents more than half of all production in countries like the United States and one third in the EU (Rossetto 2023d), many technologies are more expensive than traditional steelmaking techniques. Despite some reports that the marketplace is ready to pay a premium for green steel produced with recycled content (Taylor 2023), there is a pressing need to better understand the incentives that would be required to accelerate its development.

2.3 Calculating the social costs and benefits

Integral to the study of incentives and intervention in the markets is an understanding of the social costs and benefits. The framework for this section is the notion of social cost, or externalities. These are costs arising as a result of social, environmental or economic harm caused by private production decisions, for which those private entities are not required to pay (Coase 1960, Parisi 2004) . This applies equally to understanding of the status quo as it does to the options to intervene, which are in effect, attempts to compensate for the negative externalities (Sandmo 2000, Stavins 2003). These issues will be explored in the subsequent sections.

2.3.1 Definitions of efficiency, utility and welfare

One of the central issues emerging within the literature is our limited capacity to measure the aggregate effect of transactions and commercial interactions on collective welfare. Monetary values are useful wherever they are both available and reliable (reliable in the sense that there is actual evidence of parties transacting rather than simply saying without obligation to purchase what they believe they might pay for something, as one might observe in surveys that attempt to capture willingness to pay). This is primarily due to the ease with which they allow comparison of the value of one good with that of other goods (Posner 1986, Calabresi 1991, Mathis 2009).

Monetary values also allow for price discovery in the context of trade and transactions between economic actors. Monetary values are limited, though, in that they do not capture or quantify everything that might enrich the lives of people. Accordingly, economists and economic philosophers developed the concept of *utility* following centuries of debate, discussion and refinement (Moscati 2018, Moscati 2020).

Utility remains largely a theoretical pursuit and does not necessarily provide a fundamental tool with which one can quantify welfare. Pre-eminent economist Professor Ronald Coase (1988 p.2) described it as a "…*non-existent entity, which plays a similar part, I suspect, to that of ether in the old physics*". Coase's view was that utility was an acknowledgement that people sometimes do things for non-monetary benefit, though it is not a useful metric at the disposal of policy makers to assess the relative merits of intervention options.

The next important concept is that of *efficiency*. There are essentially two main forms of efficiency of relevance in the sense that they are popularly and contemporarily used by economists and policy makers. First is the definition originally put forward by Pareto (1906), who suggested it be defined as a state in which a reallocation of resources in a given economy cannot be made without causing harm to at least one person. This is an ideal state. The other is that espoused by Hicks (1939) and Kaldor (1939) later introduced a qualification to efficiency, recognising that having winners and losers is effectively inevitable in any resource reallocation decision. Calabresi (1991) supported these notions, suggesting that any move from the status quo are always to someone's advantage and another's disadvantage; limiting the relevance of Pareto. Kaldor-Hicks efficiency, therefore, seeks to determine the increase in welfare across a society net of any harm caused by reallocation of resources. Harm itself is, therefore, a term of fundamental importance when considering welfare, as it can be considered in practice as a negative form of utility. It is akin to damage or to being made worse off by an event or an action carried out by another part.

2.3.2 Challenges in quantifying welfare

Notwithstanding the merits of efficiency, an ongoing debate exists about what the best way is to measure welfare, what information to use and where to define the boundaries both geographically and inter-generationally. Efficiency is seldom used in public discourse and in popular politics. In fact, there is often a temptation to reduce calculations of the welfare of a society to a monetary equivalent, with Gross Domestic Product (GDP) – the sum value in a given currency of total production within a given geographically or politically defined area - often used as a proxy for determining whether a society is relatively better off or worse off from year to year. GDP is largely inadequate, however, for capturing social impacts and representing the true accumulated capital within as well as performance of an economy (Helm 2015).

This has led to the development of methodologies such as social accounting (Edey, Peacock et al. 2003) and novel means of accounting for changes in capital stock such as natural capital (Helm 2019, Fairbrass, Mace et al. 2020). Sandmo (2000) and Alemanno (2013) noted that a common method of dealing with efficiency determinations in the setting of public administration is that of the *cost-benefit analysis* (CBA). CBA, in effect, seeks to determine the overall value of a given intervention – whether it be a project or a planned law or regulation – as a sum of all its benefits and costs. It is a measure of efficiency taking regard of the negative externalities that the intervention is likely to create.

Both cost-benefit analyses and estimates of indicators such as gross domestic product are limited by the geographical or political boundaries that delineate their scope (Helm 2011, Alemanno 2013). An intervention introduced in one political jurisdiction can cause a negative impact in another. This has been shown in the area of international trade in waste where problematic waste is moved from one country to another (Kellenberg 2015). Another example has been shown in the area of greenhouse gas regulation, where some studies suggest countries that have successfully reduced their direct or scope one greenhouse gas emissions have actually increased emissions in other countries as a consequence of their consumption (Barrett, Peters et al. 2013).

A welfare economist ought to be interested in the impact of a society's activities not only within the society itself but also beyond its political or geographical boundaries. However, the primary responsibilities of policy makers and lawmakers relate to matters within their constitutional or sovereign control (Makinda 1998, Goodman and Jinks 2003).

2.3.3 Summary

Being aware of how to define and then measure the social costs and benefits is important for the study of incentives, with those that may be used in construction and demolition waste management no exception. A number of studies have identified that there are social costs and benefits can occur when construction and demolition practices are altered (Iodice, Garbarino et al. 2021, Liu, Li et al. 2021, Magrini, Dal Pozzo et al. 2022), though few have considered the macro-level consequences to a society of doing so. This is important as one seeks to consider the question of how to improve incentives for resource recovery and utilisation in construction and demolition waste sector.

2.4 Methods of intervention

According to the Concise Oxford Dictionary of Current English (1976), an incentive is "*a thing that motivates or encourages someone to do something*" (Page 176). An incentive could therefore be something mandatory, where there is the threat of a legally enforceable penalty if one does not carry out the activity. It might also be a voluntary motivator, which could range from a financial incentive all the way through to a sense of moral duty. As suggested by Coase (1988 p.28), "…*since, by and large, people choose to perform those actions which they believe will promote their own interests, the way to alter behaviour in the economic sphere is to make it in their interest to do so*". Mathis (2009) summarised the work of classical economist Adam Smith in suggesting that there were four controls on self-interest that could lead to incentives for parties to change their behaviour: (i) sympathy and the impartial spectator, (ii) social and ethical norms, (iii) positive law and (iv) the forces of competition.

There are two branches of economics that are relevant to this research. The first branch is concerned with markets; and the ability to harness the forces of private individuals and organisations, acting in their own self-interest, to develop and implement solutions. This branch favours individual liberty and freedom. The second is concerned with the welfare state, an approach that seeks to modify market outcomes on an assumption that markets do not always maximise the welfare of the societies they serve. This branch recognises there are limits to individual liberty and freedom as a means of maximising the overall welfare of a given society (Cousins 2005, Andersen 2012).

Beginning then with the first of the two branches, being markets, Friedman (1962) summarised a general proposition that when parties are permitted to enter into voluntary transactions they tend to maximise their own welfare and feel better off as a result of the transaction. After all, if a party felt it would be worse-off as a result of a transaction, it could choose not to participate. Consequently, as one aggregates the utility of all private transactions across a given economic area, overall welfare increases.

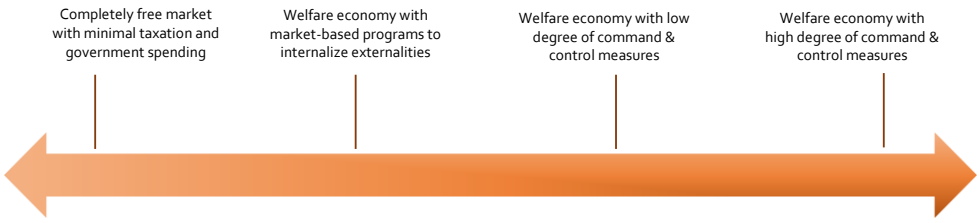
Friedman qualified this proposition, however, suggesting it applies in cases where the transactions do not impose costs, sometimes known as externalities, on any third parties. In other words, even though a private transaction may make the parties to the transaction better off, there are cases where others suffer harm. Friedman held these cases where such harm is created, there is a case for government intervention. It is important to note that Friedman was sometimes criticised for taking too favourable a view of the virtues of the private enterprise system (Rayack 1987), though it is notable that he received a Nobel Prize for his work. It is also clear that Friedman was not opposed to the idea of government intervention, nor the broader objectives common among those who espouse the welfare state.

The second of the two branches is that of the welfare state. According to Andersen (2012), the welfare state is one in which a minimum level of welfare is guaranteed to its citizens, by government, to protect those citizens from the most negative outcomes that they may otherwise experience. Andersen sets out that welfare states achieve this in part from raising taxes, so that the state has an income stream upon which to budget for its welfare programs. There are other protections that do not require any government funding, rather they mandate specific behaviours or technical solutions or the so-called *command and control* measures. Cousins (2005) identified reasons that explain why welfare states emerge, one of which is that they are a consequence of very advanced levels of capitalism and industrialisation. In that sense, a welfare state theory is not necessarily diametrically opposed to markets. Rather, it is one that operates in parallel with functional markets and, in many cases, depends on markets to generate the funding needed via taxation. Coase (1988) acknowledged that the case for command & control mechanisms was sometimes enhanced by the transaction costs of the market-based alternatives. That is, there are occasions in which transaction costs associated with dealing with multiple individual parties make market-based solutions unworkable.

Either way, the lines that delineate market-based approaches from the welfare state are sometimes blurred. Both are essentially concerned with "*motivating someone to do something*" though affording differing degrees of freedom. This recognition suggests that there is a continuum along which different kinds of incentives can be placed according to the level of freedom they afford.

The continuum is represented in Figure 4 below, with the lighter shade of orange on the left-hand side of the continuum representing the higher degree of freedom compared to the darker right-hand side.

Figure 4 – Indicative continuum between free market and welfare state solutions



It is within the context of this continuum that the different kinds of incentives are presented in Sections 2.4.1 to 2.4.7 below. Included at the end of each incentive description are the boundary conditions that apply to it.

2.4.1 Voluntary action

Voluntary action is the form of incentive that affords the most freedom. In most cases, it represents the status quo where participants in a market are free to transact wherever there is opportunity; and it is in their best interests to do so. In the event of an externality arising from those transactions, it would be enough for the parties to be aware of the harm they are creating for them to act to either eliminate the externality, provide compensation to the parties negatively affected or seek to avoid business in future that creates such externalities. The reasons for doing so may include that customers prefer to choose suppliers who do not create externalities. This can be regarded as a form of market-based solution, though one in which no intervention is needed and that relies on voluntary action by private entities (Friedman 1970).

The existence of competition is crucial in this context. Competition has been held by a number of classical economists, particularly such as Smith (1910) and Marshall (2013) as a meaningful constraint on self-interest. The argument is linked to the issue of price convergence in the context of markets. Markets, in which there is insufficient competition, lend themselves towards there being dominant buyers and sellers who are able to maximise private interests at the expense of others.

For example, if there were insufficient competition on the supply of a product or service, it would be possible for the incumbent supplier to elevate the price as though there were less supply available. Similarly, if there were insufficient competition in demand for a product or service, the incumbent customers could behave in such a way as to reduce demand and lower prices. For there to be perfect competition, there also needs to be perfect information among participants (Buchanan 1969, Coase 1988).

If there are different levels of information available to different participants, it is possible that an *arbitrage* may emerge. As example of an arbitrage is where the same physical commodity can be traded on two different market platforms – for argument's sake, let us call these Platform A and Platform B. It may be that there is a different price on both market platforms, which we shall call Price A and Price B, whereby Price B is 5% greater than Price A, though not every participant is aware of this spread (with spread being the difference in magnitude between Price A and Price B). In such a case and assuming there were no additional costs associated with accessing or transporting goods from Platform A to Platform B or the time taken to do so, a participant with access to such information could purchase goods from Platform A and re-sell them on Platform B, realising a gross margin of 5% almost instantaneously. Arbitrages can continue for as long as imperfect information exists, though over time as the existence of such a spread is disseminated, the arbitrage eventually disappears (Zaremba 2019, Zaremba, Szyszka et al. 2020). This is a very important point. It means that market participants, when engaging in markets where there is adequate competition on both supply and demand sides of the given product or service, as well as adequate information available to market participants, will naturally encourage transactions that are both efficient and utility-maximising on both sides. This reduces the scope for market participants to be left worse off as a consequence.

There is, however, some degree of subjectivity on these principles. For example, what does adequate mean in this context? Can it be quantified? This has led competition regulators and courts to seek additional definitions for markets when deciding on cases or situations where intervention may be necessary to increase the contribution of markets to societal welfare. For example, it would be relevant to determine how possible it is to substitute a supplier or buyer in a market in order to ascertain the degree of competition that exists (Baker 2007, Ferro 2019, Australian Competition and Consumer Commission 2020).

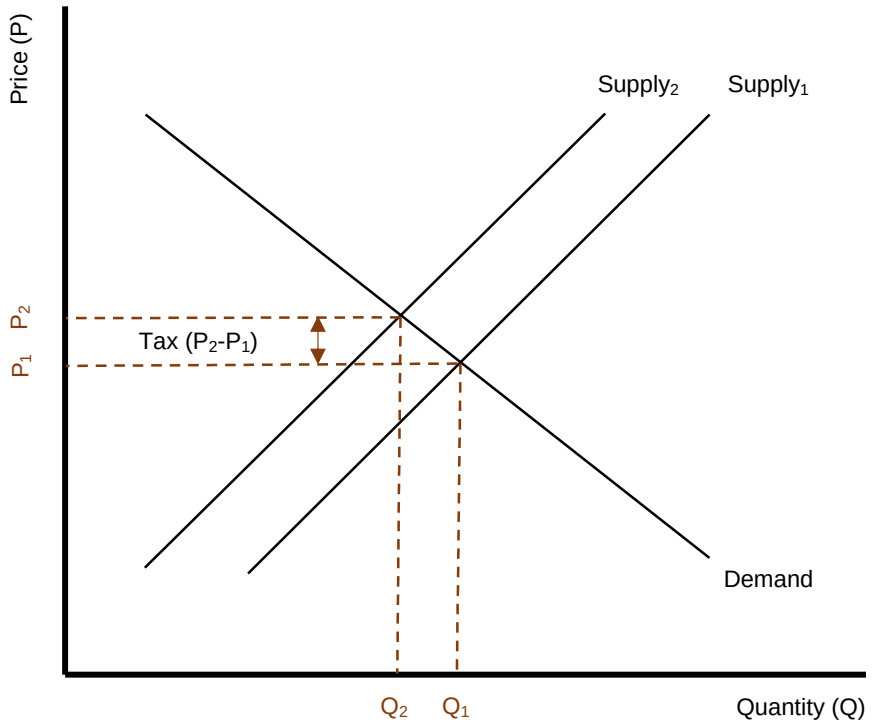
Kelly (2022), Pickin, Wardle et al. (2020) and Thomson (2021) also noted that, while there is a high concentration of privately owned businesses present within markets like the construction and demolition waste ecosystem, there are some instances where competition is limited. It is possible that some transactions, which appear at the outset as voluntary, come about as a consequence of existing systems, regulations or case law precedents. This adds complexity because there may already be some instruments affecting activity.

The main characteristics of voluntary incentives mechanisms are, therefore, summarised as participants (a) have the freedom, authority and capacity to transact, (b) have some choice over whether and how to transact and (c) are not being compelled to transact by another rule, regulation or other means.

2.4.2 Taxation and subsidy

Tax (and subsidy) programs have been developed over the years to either increase the cost of harmful activities like pollution or decrease the cost of beneficial ones like research and development (Sandmo 2000, Helbling 2020). In the case of harmful impacts, the activity that creates the externality is not prohibited but rather subjected to a tax. Originally espoused by Pigou (1920) and elaborated by Buchanan (1969), the tax is applied as a factor of production, such that the overall price of the product is increased. In economic terms, this has the impact of reducing demand for the product. If less of a product is produced, the fewer externalities will be generated. The process is reversed for activities that create a positive social benefit are financially subsidised. Graphical explanations are provided in Figure 5 and Figure 6 below.

Figure 5 – Representation of a Pigouvian or corrective tax



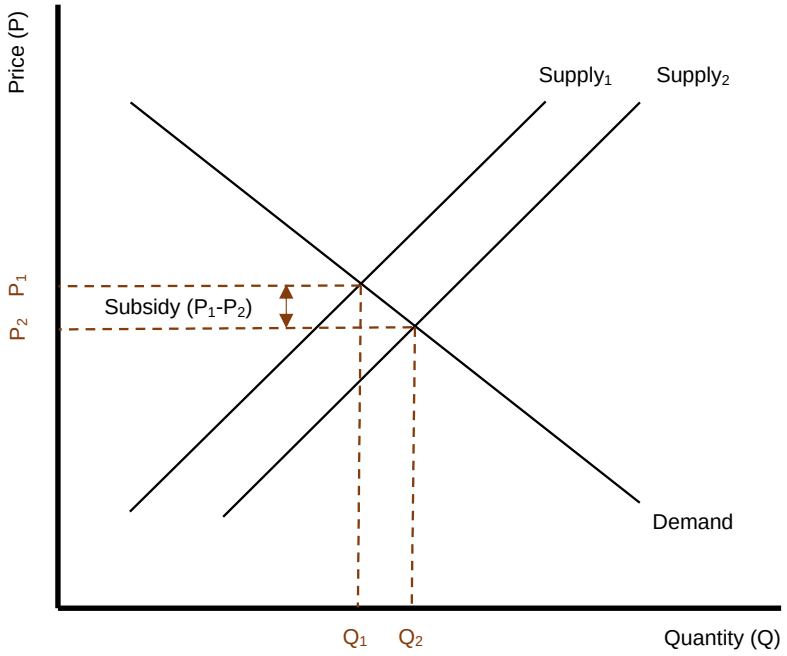
Source: Adapted from Pigou (1920) and Buchanan (1969)

In Figure 5, the demand curve for a product or service that is known to generate a negative social externality – which could, for example, be a pollution-causing industrial activity - is shown by the demand curve. It illustrates that the more of the product or service that is produced, the lower becomes the price. The equilibrium state shown is that at which the quantity Q_1 is produced at the price P_1.

A Pigouvian tax applied to the product or service is then added as a factor of production, raising the price to P_2. Given the demand curve, the quantity of the product or service produced will reduce to Q_2. It also follows that for every unit of the product or service sold, a tax equivalent to the value of $P_2 – P_1$ will be raised government.

In addition, the tax revenue collected can be used by the government to either (a) compensate the person(s) suffering harm, (b) subsidise other activities that produce positive externalities or (c) spend in other areas of political priority.

Figure 6 – Representation of a Pigouvian subsidy



Source: Adapted from Pigou (1920) and Buchanan (1969)

A Pigouvian or corrective tax can also be reversed. Accordingly, Figure 6 illustrates the concept of a Pigouvian subsidy. The demand curve for a product or service that is known to generate a positive social externality – which could, for example, be research and development activity - is shown by the demand curve. The equilibrium state shown is that at which the quantity Q_1 is produced at the price P_1.

A Pigouvian subsidy is then applied to the product or service, reducing its price to P_2. Given the demand curve, the quantity of the product or service produced will increase to Q_2. It also follows that for every unit of the product or service delivered, a tax equivalent to the value of $P_1 - P_2$ will be spent by the government.

Taxation and subsidy programs are subject to the influence that other self-interests can have on the processes of decision-making in both public administration and the private sector (encompassing operational decisions as well as capital allocation). These influences can be *internal*, such as the interests of individuals and officials engaged in public or enterprise administration which are sometimes referred to as the theory of *public choice* (Rowley 1993, Mueller 2003, Kliemt 2012).

There are also external forces that are part of a broader phenomenon of the *political economy*, whereby capital allocation and operational decisions may be unduly influenced by vested interests, which lobby decision-makers to achieve favourable outcomes for the self-interest of the party or parties they represent (Jevons 2013, Marshall 2013). Forces of the political economy are also well known. Scholars like (Coase 1960) suggested that revenues collected by public authorities, once accumulated in centralised accounts, may be spent in ways that are subject of other forces such as political priorities of the day; and may not necessarily go directly as compensation to harmed parties.

This is a point supported subsequently by many authors such as Calabresi (1991) and Hervés-Beloso and Moreno-García (2021) and Deryugina, Moore et al. (2021).In the public administration context, this can occur at multiple levels and be quite indirect. For example, a regulatory program that aims to tax negative externalities raises funds, which in a pure welfare sense ought to then be used solely for the purposes of compensating those who have suffered harm as a direct consequence of the externality's generation.

In practice, the funds collected more often than not become part of an expenditure prioritisation process of government that takes into account political objectives as much if not more so than compensation and corrective justice. These forces, when they distort attempts to compensate for harm caused from private and self-interested business activity, can act as a limit on the attainment of efficiency within a given society (Hicks 1939, Kaldor 1939). Recognition of this led Coase (1988 p.26) to describe the normal public administrative authority as "…*ignorant, subject to pressure and corrupt*".

Public choice is a well understood and research concept that studies the behaviour of individuals within larger entities such as government bureaucracies or corporations, which may distort the decision-making. In its most extreme cases, public choice can explain how individuals may sway decisions for their own self-interest (for example, to advance their own career or personal level of power) in preference to the interests of the public or the shareholders.

Helbling (2020 p.4) noted that manifestations of the theory of public choice have introduced moral hazard into the context of public administration, which in some respects is its own form of externality. Helbling stated that "…*decision makers maximize their benefits while inflicting damage on others but do not bear the consequences* ". Parisi (2004) suggested that even the courts may be subject to similar forces of distortion, suggesting that judges may be influenced, in some part, according either to their values or the basis on which they were employed (which in some cases involves nomination via the executive arm of government). This is notwithstanding the particularly strong assertions from Posner (1986) and Calabresi (1991) that efficiency was a central consideration for the courts when deciding cases.

Attempting to determine who benefits and who does not within the context of taxation and subsidy programs applied in the construction and demolition waste industry is complex. Hogg (2006) and Calvo, Varela-Candamio et al. (2014) noted that levies made for landfill had the characteristics of taxation. Shooshtarian, Maqsood et al. (2020) found that taxation and subsidy programs were not always the most popular within industry. The beneficiaries will be those whose products and services are made more competitive due to the tax or if they are the recipients of the subsequent spending. The losers will include those whose products or practices are now subject to the tax; and those whose products are less competitive as a direct consequence of the tax (Asare, Oduro Kwarteng et al. 2020).

The main characteristics of the taxation scenario are, therefore, that there is (a) a law, rule or regulation that introduces a tax on specific business operations and (b) the tax alters the competitive landscape of the market concerned.

2.4.3 Public investment

Another instrument is that of public investment, though the degree to which it acts as an incentive depends on how the public investment is deployed. The first form of public investment is that of state ownership of business enterprises, so it is primarily and equity-style investment.

Several authors have identified state ownership as a means of correcting a market failure, either because no market exists or that there are other compelling reasons for the state to become involved for the longer term benefit of a given population (Organisation for Economic Cooperation and Development 1998, Ishak, Ilmar et al. 2021). Thomson (2021) identified that many publicly owned enterprises are active in the market within Australia's construction and demolition waste ecosystem, which is largely a legacy of public agencies like local governments being the original owners of landfill sites.

Another form of public investment that can confer a financial benefit to private parties – and therefore act as an incentive – is through the provision of concessional capital. Rossetto (2017) identified that concessional capital can be provided in various forms, from grants to loans with different interest rates and tenors, to investment guarantees and even derivative risk management instruments such as contracts for difference. It has been noted that the provision of concessional finance to projects via public and private entities such green or development bank is increasing across the world driven by the emerging area of climate finance (Heerdt 2014, Hong, Karolyi et al. 2020). The federal government in Australia, for example, provides finance to the sector via the Clean Energy Finance Corporation, which is a state-owned financial institution (Clean Energy Finance Corporation and Arup 2021).

The main characteristics of public investment are that there is evidence of either (a) state ownership of business enterprise or (b) state investment being channelled into private sector activity. It is primarily the instance of the second of these two, where the commercial terms of the allocation of that finance are concessional, that acts as an incentive. However, there can be a degree of incentive within state ownership as well, particularly of an equity investment is used to reduce the risk exposure of private sector investors, such as first loss capital.

2.4.4 Regulation

Regulation is a form of rule that prohibits certain activities that create negative externalities, or makes other actions mandatory (Sandmo 2000). While limiting the freedom of private interests might appear to be costly, the principal argument in favour of them is the savings in transaction costs like the issue explored by Coase (1988). Stavins (2003) also used the term *command and control* to describe direct regulation instruments, which is also in the preamble to this chapter. Regulations are generally statutory instruments, which means they are applied under statutory laws. They can take the form of a prohibition of certain activities or practices, or a mandate that those activities or practices be implemented (Latham, Schwartz et al. 2011). While regulations generally remove freedom for market participants over the issues they are designed to control, such instruments do still act as incentives. A market participant may be "…*motivated or encouraged to do something"* to be compliant with law and to avoid either a penalty, sanction or in some cases a criminal charge.

An example of this kind of instrument can be found in building design, planning and construction standards, which often prescribe specific activities that either must occur or that must be avoided. Within these measures, there is implicit acknowledgement that the users of the building along with the broader community will have no way of organising themselves to negotiate with the owner. Consequently, requiring that certain construction practices be followed in order prevent negative externalities from occurring in the first place can be efficient. There are winners and losers from direct regulation. Winners may include the organisations supplying products and materials now subject to a mandate. The losers may include those developers whose projects may now cost more because of the mandate. The exception within building standards is that some regulatory regimes, like that of Australia, permit a performance-based pathway to compliance. This means that actors are provided a degree of design flexibility to achieve the outcome, along with a deemed to satisfy pathway, which has a more specific, regulatory character (Council of Australian Governments 2007, Australian Building Codes Board 2011).

The main characteristics of regulation are that there is (a) a law, rule or regulation affecting operations and (b) the law, rule or regulation has the effect of limiting the flexibility of market participants either by requiring certain activities take place or preventing other activities.

2.4.5 Common law

Common law can be viewed as an extension to the default scenario in countries where this legal system applies, such as Singapore, Australia, the United States and the United Kingdom, for example. Private entities and individuals are afforded the opportunity to settle disputes about harm caused by externalities via the courts. As scholars such as Posner (1986), Calabresi (1968) and Parisi (2004) have noted, court decisions, however, often create a legal precedent. This precedent may then act as a rule that influences the behaviour of private firms in the future, in much the same way as a regulation.

Common law may reveal certain liabilities that arise for businesses if they generate externalities and in doing so act as a deterrent (Coase 1988). Deryugina, Moore et al. (2021) and Hervés-Beloso and Moreno-García (2021) found that liabilities defined under common law are not necessarily prohibitive and can create a basis for parties affected by negative externalities to negotiate with businesses known to be causing them. Coase (1960) had also noted, notwithstanding, that complexity in such negotiations can become so great that the transaction costs render it difficult to reach an agreement.

Parties may be negatively impacted by both a common law case itself - including but not limited to the costs of pursuing the case itself - and the impact of the legal precedent. This has led some authors such as Posner (1986), Parisi (2004) and Mathis (2009) to explore the extent to which the judiciary takes efficiency into account when deciding the merits of a case.

In this context, the main characteristics of the common law scenario contain the characteristics of (a) an outcome of a prior legal dispute that has created a precedent that affects business operations and (b) a precedent implies the allocation of a liability to at least one party to a transaction.

2.4.6 Market-based approaches

Market-based approaches seek to harness the forces of risk-taking private entities to achieve an environmental goal. According to Stavins (2003 p.358), market-based measures are "*regulations that encourage behaviour through market signals rather through explicit directives*". Within a market-based program, the price is determined by market forces – that is, firms in competition with one another, where there is a clear interaction between supply and demand - rather than a centralised agency setting the price level as would be the case with a tax. Market-based systems often depend on the existence of legally binding volumetric targets for environmentally desirable outcomes, which helps to set the level of demand for the product or practice that is the subject of the program by creating a scarcity of the outcome in question. There is also typically a non-compliance charge, which creates the incentive to comply. Authors have noted that taxation programs are like market-based incentives, with the main difference being that in the former, it is government that determines the price or level of the tax. The assumption is that competition, whereby suppliers and customers have choices and are free to negotiate, induces optimal allocation of resources (Hart 1983, Sandmo 2000).

The main characteristics of a market-based system are that: (a) there is a legislated environmental goal, (b) there is a means of assigning that legislated environmental goal to corporations and individuals as a liability, (c) a charge for non-compliance exists, (d) there are opportunities for buyers and sellers to enter and exit the market providing competition and (e) the price of the environmental benefit is determined by the market.

2.4.7 Taxonometric approaches

A final form of intervention that has arisen in recent years is that of the taxonometric approach. A taxonomy is a list of activities that are considered to fit the profile of sustainable or circular economic, which have served to simplify the process of financial market participants determining what is sustainable and what is not (Dimmelmeier 2023, Moneva, Scarpellini et al. 2023).

This has become especially prevalent in sustainable finance and involves mandatory guidelines on product disclosure as well as standards for labelling. This makes the taxonometric approach, at its core, an umbrella intervention to address information asymmetry. In this respect, it relies upon the incentive that, once market participants have better information, they will make decisions that promote positive externalities without other constraints. The European Commission (2020) and (2022), for example, released guidelines for sustainable investment disclosure and included a taxonomy within that approach. The taxonomy includes six areas in which defined what constitutes a sustainable investment. These are climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, and protection and restoration of biodiversity and ecosystems. In addition to the six areas, the regulations require proponents to demonstrate that investments contribute 'no significant harm', which means, in effect, that negative externalities not be created.

Scholars such as Agoraki, Giaka et al. (2023) found that the taxonometric approach was having a positive impact, noting a that European firms disclosing more information generally have lower Environmental, Social and Governance (ESG) risk profiles. Setyowati (2023) and Singhania and Saini (2023) noted that this kind of taxonometric approach was growing its popularity globally. Among the main features contributing to this popularity has been the simplification of what would otherwise be complex technical areas, into a form that is digestible and comprehensible for mainstream financial services firms, investors and capital markets participants. However, the simplicity of the approach does not necessarily remove the complexity of the underlying subject matter. Soh Young and Schumacher (2021), for example, noted that over-simplification allowed for claims to be made that were either unverifiable or untrue. Labelling itself does not change capital allocation, nor the course of business-as-usual activity, so it is at risk of being perceived as greenwashing.

2.4.8 Summary

There is a wide choice of instruments available to create incentives for more resource recovery and utilisation. Specific applications in the context of construction and demolition waste - and green steel – are not well understood, nor is the relative or absolute effectiveness of the choices. This has led to the development of the research question: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* It is also likely that, due to the co-benefits that more circular process can deliver such as greenhouse gas abatement – there is some scope for integration of these mechanisms. The next Section (2.5) will consider specific incentive mechanisms. In addition, portfolio papers one, four and five (Chapter 5, Chapter 8 and Chapter 9) have all sought to provide a review of effectiveness of different mechanisms.

2.5 Overview of financial incentive mechanisms

The following sections describe the different kinds of mechanisms most commonly used to provide financial incentives, most often at the project level, typically used to confer a financial advantage onto the activities that either produce positive environmental and social externalities or minimise them. These are revenue support mechanisms (Section 2.5.1), cost of capital support (Section 2.5.2) and negative externality levies (Section 2.5.3). In addition, Section 0 elaborates the principle of additionality, which is often – though not always – used to determine the eligibility of activities for these programs. It also provides an overview of the issues of regulatory stability and sovereign risk (Section 2.5.5), which is the tendency of host governments to change rules and regulations over time that, in fact, alter parameters on which the basic investment assumptions had been made.

2.5.1. Revenue support mechanisms

Revenue support mechanisms allow project proponents to monetise the positive impact of projects, which can in turn boost returns above investment hurdle rates (Plöchl, Wetzer et al. 2008, Lo and Cong 2022). Figure 8 illustrated the simplified effect that the new revenue stream could have on financial performance under such arrangements. In order to qualify for such mechanisms, projects generally need to be proven additional to business-as-usual.

As shown in Figure 7 (refer to Section 2.5.4 below), the implication of a project not being additional is that it is a business-as-usual, so its performance is the same as the baseline and its impact, by definition, zero. Scholars have found varying levels of success of revenue support mechanisms in supporting improvements in waste management practice. Agamuthu, Khidzir et al. (2009) found that economic incentives were among four main drivers of improved practice in Asia, along with human, institutional and environmental factors. Rasheed, Khan et al. (2023) made a similar conclusion, though called for scaling up of incentives. Asare, Oduro–Kwarteng et al. (2022) found evidence that these programs work more effectively than levies and charges. Peng, Lu et al. (2022) highlighted the potential for market-based systems to be expanded beyond greenhouse gas emissions and to the recovered materials.

2.5.2. Cost of capital support mechanisms

Cost of capital is an important expense for businesses and is used in investment decision-making. Businesses use the weighted average cost of capital (WACC) as a metric that looks at the relative costs of its equity and debt financing - and the ratio at which both are used – though often defer to return on equity as the basis for investment decisions (Frank and Shen 2016, Steffen 2020).

Economic incentives can be offered to improvements in waste management practice in the form of cost of capital support mechanisms. O'Dwyer and Unerman (2020), Calvet, Gianfrate et al. (2022) and Caldecott (2022) noted the impact at the macro-level on cost of capital arising from central bank practices that allocate more risk to polluting activities. These kinds of macro-level activities can have a corresponding impact on capital allocation and investment decision-making, which some scholars note is among the potential outcomes of applying and enforcing by central banks of the recommendations of the Taskforce for Climate-related Financial Disclosure (TCFD).

At the project level, scholars such as Rossetto (2017), Tao, Zhuang et al. (2022) and Amighini, Giudici et al. (2022) identified the broader movements in green and climate-themed finance. A number of instruments – or windows in the case of offerings from dedicated impact funds – were identified that can be used to provide financial incentives for waste management projects. These include grants that subsidise the capital cost, provide interest rate subsidies, underwrite investment guarantee, provide liquidity for financing that is not otherwise available in the market either by the tenor or volume of the financial commitment, or introduce subordinated equity schemes – in which one investor, such as a climate finance fund, agrees to wait until another investor has been paid out its return or dividends before seeking its own – are all examples of cost of capital support mechanisms.

2.5.3. Negative externality levies

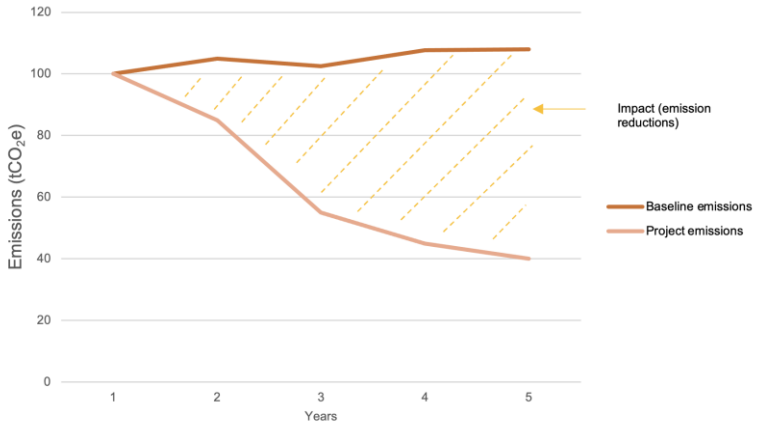
As set out in the introduction, other instruments broadly termed negative externality levies can provide incentives for improved waste management practice and resource recovery.

These arise because polluting activities attract a charge, which can be sufficient for actors to look for alternatives that do not attract the levy. Jiménez-Rivero and García-Navarro (2017), Shooshtarian, Maqsood et al. (2020) and Matheson (2022) are among a number of scholars that have validated landfill charges – as an example of this kind of instrument - as a driver of resource recovery. Wu, Zuo et al. (2020) found that there is a tendency for waste disposal activities to seek out the lowest cost alternative, where there are differences in charges between jurisdictions, implying that higher landfill charges do not necessarily guarantee more resource recovery. Others studies found that cap-and-trade programs like the European Union's emissions trading system could produce the same effect as negative externality levies, though the price signal to induce resource recovery as an alternative to landfill can be muted if those systems provide free allocation to incumbent emitters (Sandbag 2022, Rossetto 2023a).

2.5.4. Additionality

A fundamental concept in determining which activities are eligible for financial incentive programs is that of additionality, abbreviated from the policy intention that project activities be additional to business-as-usual practice. Figure 7, taken from Rossetto (2023c), illustrates the impact of additionality in the context of a greenhouse gas emission reduction project, where the emissions of the project scenario are below the baseline. In such cases, provide the project is proven to be a genuine departure from business-as-usual, impact is the difference between the baseline and project emissions.

Figure 7 – Illustration of the impact of a GHG reduction project that is additional

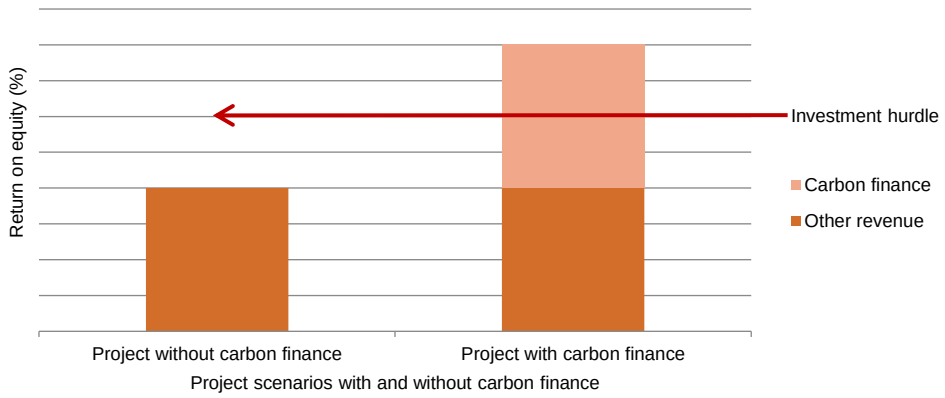


Source: Rossetto (2023c p.6)

Quantitative and objective approaches to additionality assessment have been developed for market-based systems to incentivise emission reductions, often referred to as *carbon finance*. Greiner and Michaelowa (2003), Dutschke and Michaelowa (2003) and Carmichael, Lea et al. (2016) analysed an approach initially used within the Clean Development Mechanism (CDM) - a project-based mechanism under the UNFCCC's 1997 Kyoto Protocol – that involved use of *financial additionality analysis*.

The aim of financial additionality has traditionally been to demonstrate that a project fails to meet a market-standard investment hurdle rate without inclusion revenues from carbon finance; and thereby the default scenario is that the status quo prevails with a higher emissions baseline. Figure 8, taken from Rossetto (2023c), illustrates how carbon finance allows an energy generation project's modelled return on equity to be increased above a hurdle rate of return. In other words, before carbon finance revenues are considered, the project return is insufficient to meet the hurdle rate and therefore, assuming rational investment decision-making, would not proceed. In such cases, a project can be considered financially additional if additional revenues support its return to the extent it can achieve a nominal investment hurdle rate.

Figure 8 – Illustration of carbon finance's impact raising returns above hurdle rates



Source: Rossetto (2023c p.8)

Investment decision-making integrates different sensitivities, where the revenues that projects are able to generate are assigned probabilities (Rossetto 2014, Carmichael, Lea et al. 2016). In this respect, carbon finance can become important at the margin of meeting a project's investment hurdle rate. A decision to not register a project to generate carbon finance revenues is, in effect, assignment of 100% probability that it will generate zero revenues from this item over its lifespan. However, under certain scenarios of probability, the revenues are enough to move the project's return above a nominal hurdle rate.

Other forms of additionality deployed in the CDM involved *barrier analysis*, whereby proponents could seek to demonstrate that another barrier, such as unfamiliarity of new technology, prevented its deployment. This later included a simplified financial additionality test to prove a project was not the least-cost alternative (CDM Executive Board 2012). There have been strong critics these kinds of additionality assessment processes. Schneider (2009) looked at 93 projects registered under the CDM and concluded that assessment was too subjective and is therefore difficult to validate. Streck (2011) advocated the need for establishing new criteria for testing additionality to remove the potential for controversy. This included development of a so-called positive list approach, in which public agencies determine ex ante what kinds of projects over a given timeframe are additional – and, by definition, not common practice – so that additionality assessment can be limited to verifying that a project deploys a specific technology.

Baxter and Gilligan (2017) noted that the approach deployed in Australia under its Carbon Credit (Carbon Farming) Act 2011 used the positive list additionality approach, though the authors also identified weaknesses especially in determining whether some project kinds – including landfill gas projects - were truly additional. In response, the Australian government commissioned an independent review, which concluded projects were additional, though revisions to baselines on second crediting periods is warranted (Chubb, Bennett et al. 2023).

Applications of additionality are not limited to carbon markets. Luukkonen (2000) set out applications for additionality to support allocations of public funding to private entities for research and development. It involves creating a counterfactual baseline scenario of what would have happened were it not for the project, which serves as a basis for justifying the use of public funds to support private activity. Carter, Van de Sijpe et al. (2021) noted the important role it plays in influencing the investment decisions made by development finance institutions, though it the authors found evidence of systemic bias. This linked to the subjectivity of definitions of what constitutes additionality. Without a clear way of demonstrating additionality, the integrity of the intervention can be brought into question.

Notwithstanding, additionality assessments remain an important requirement for incentive programs, especially revenue support mechanisms (refer to Section 2.5.1 for further detail). Scholars such as Michaelowa, Hermwille et al. (2019) have argued that, notwithstanding experiences within the CDM, additionality tests remained vital for the new mechanisms under the Paris Agreement to ensure *hot air credits* – credits related to projects that do not represent a shift in business-as-usual practice - are avoided.

2.5.5. Regulatory stability and sovereign risk

Financial incentives that are generated using the mechanisms described in this section seek to influence investment decisions. In many cases, the investments are in the development of long-lived infrastructure. That means investment horizons are often 10 years or more; and may need to make assumptions about cash flows for as many as twenty years ahead.

McKibbin and Wilcoxen (2002) and Luthi and WÜStenhagen (2012) identified that stability was therefore crucial in cases where the mechanisms exist as a result of regulation or legislation. Perception that there is likely to be change to the laws and regulations that create mechanisms designed to influence investment decisions may result in the economic benefits being discounted.

Ortino (2018) noted that it is the sovereign right of governments to change laws and policies as needed from time to time. Brooks, Cunha et al. (2022) identified that this could occur as a result of unexpected changes in political and economic conditions in a given jurisdiction, as well as due to changes in government that come about through democratic processes like elections. This means the extent of regulatory stability is a measure of the sovereign risk applicable to given countries. If support mechanisms are designed to influence capital allocation and infrastructure investment where the outlook may be over periods as long as 20 years, Zannoni (2020) identified that a balance is needed between the private sector's need for regulatory stability and the host country's right to adapt regulations to evolving societal needs.

Boomsma and Linnerud (2015) and later Boute (2020) considered the issue in some depth in regard to revenue support mechanisms for renewable energy. Policy risks may lead either to (a) premiums being built into investment decisions, which leads to higher prices for the country concerned, (b) investments not being made at all. One way to mitigate the premium is to commit to granting protection to projects that have already begun – that is, had commenced construction or even advanced to commercial operation - so that only new investments are exposed to policy changes. This kind of commitment by the host country limits adverse ex-post changes; and affords protection to projects and investments that had been committed based on a given set of policies.

Notwithstanding, there have been many instances with support mechanism programs where ex-post changes have occurred without compensation being paid to affected projects (CDM Policy Dialogue 2012, Jotzo, Jordan et al. 2012). Luethi (2010) showed in the case of renewable energy that premiums added to account for policy risk in some cases may become more important to a project's viability than the value of the electricity being sold.

2.5.6. Summary

This section considered literature about the mechanisms available to create financial incentives to adopt more sustainable practices. It considered the three main categories of mechanism, being revenue support, cost of capital support and negative externality levies. In each of these cases, the mechanism purpose is to improve the financial returns of what would otherwise have been marginal projects or activities and move them above a nominal investment hurdle rate. In this respect, the mechanisms seek to reward projects and activities that are additional to business-as-usual practice. This is a concept that is broadly known as *additionality*, which literature suggests has been applied with more discipline and structure to revenue support than to cost of capital support or negative externality mechanisms.

Finally, regulatory stability emerges as a critical factor. In many cases, the support mechanisms are established by policy or regulation and seek to influence the investment decisions of private actors into long-lived infrastructure. Therefore, ex-post changes to the policies or regulations that give them effect can undermine confidence among the very same private actors they seek to influence. While it is a sovereign right for host countries to change regulatory or policy settings, in the most extreme cases such changes – if applied to existing investments – will undermine the case to invest in new projects or result in sovereign risk premiums that could result in higher costs to the final consumers in the host country. This would work against the very nature and purpose of the mechanisms; and introduce an element of counter-productivity.

2.6 Applicable theories

The final part of the literature review is to explore the theories that influence innovation at the level of the firm, whereby incentives either exist or are created that compel firms to innovate in order to maximise their interests. Mathis (2009) held that there were various controls on self-interest that could lead to incentives for parties to change their behaviour, such as social and ethical norms that apply to the operating environment, context and marketplaces of firms, the existence of current and future laws and regulations in the jurisdictions of operation of firms and the forces of competition. In principle, the forces of competition suggest that a firm unable to keep pace with other businesses able to supply the same customers with goods and services will eventually lose business and not survive. These theories, while generally applicable, can help to explain the phenomena observed in the construction and demolition waste industry and, more specifically, steel.

The first theory of relevance is that of Market-Based Management (MBM), which is based around the notion that the primary incentive for innovation by firms is that of market opportunity. In this respect, once firms understand customer need, they seek to innovate in a way that can supply that customer need in a way that is different to competitors in the market (Gordini 2010, Ali, Kelley et al. 2020).

The second theory of relevance is that of the Porter Hypothesis, which broadens to consideration of cases in which there has been intervention within a given marketplace to correct some kind of negative externality. The Porter Hypothesis suggests that higher environmental standards adopted in one market or country will drive innovation by firms in order to comply with those standards, which in turn may lead to those firms retaining a competitive advantage in other markets (Porter 1990, Porter and Linde 1995). This has the potential to contradict claims that carbon leakage takes place precisely because environmental constraints cause a loss of competitiveness.

The third and final theory of relevance is Coase's Theory, which introduces the notion that the way in which the intervention is designed will also impact the response. It suggests that, when using systems to correct market failure that are based on property rights, the costs of addressing it will be the same regardless of how property rights are initially allocated, if transaction costs are assumed to be zero (Coase 1960, Calabresi 1968, Calabresi 1991).

These theories will be explored in more detail in the following sub-sections.

2.6.1 Market-Based management

Market-Based Management theory is a logical place from which to begin consideration of incentives and how they impact innovation within firms. Firms are continuously seeking to identify customer need; and then introduce innovation that allows the firms concerned to supply goods and services that meet those needs in a way that is more cost effective than the competition. Gordini (2010) claimed that, in doing so, firms can gain a competitive advantage.

Ali, Kelley et al. (2020) noted that there were various institutional conditions that paved the way for this kind of entrepreneurship. Start-up and early-stage businesses are an important form of firm that seeks to capitalise on market opportunity, though there are also more established firms that might seek to innovate with new products or services that address changes in the external environment and influence customer need.

Ayar Şentürk and Özkan (2023) described this process as *value innovating*, whereupon the firm's innovation targets the creation of value for customers by solving problems for which there are no viable solutions, or doing so in a way that provides a more efficient solution compared to that which was already available in the market.

Market-Based Management does not rely upon any specific policy or regulation to become activated. It comes about through the forces of competition that, as was described earlier, can represent an existential threat to a firm. As suggested by Mathis (2009), it is rational for a firm, acting on the basis of its own self-interest, to attempt to remain competitive in its marketplace(s).

2.6.2 Porter's hypothesis

Opportunities to improve construction and demolition waste management practice come about due to concerns within society and the marketplace about the negative externalities that landfilling and other traditional practices create (Papastamoulis, London et al. 2021, Purchase, Al Zulayq et al. 2021). In this context, Wang, Yang et al. (2022) drew attention to the potential for innovation to be policy-driven. In this respect, firms may seek to innovate in order to comply with policies, laws and regulations, which have been established to deal with environmental impacts or externalities.

The previous section of this thesis highlighted the legitimate need for there to be regulatory intervention, either to prohibit certain activities or mandate others, when transaction costs prohibited other market-based solutions or arrangements that afford flexibility to market participants. Furthermore, Mathis (2009) noted that current and future laws in the jurisdictions of operation create regulatory incentives for firms to take action. Latham, Schwartz et al. (2011) drew attention to the fact that regulations, especially containing environmental standards, sometimes develop in an uncontrolled and haphazard way and at various times can arise as a result of court decisions which, through common law, create legally binding precedents.

An important theory in this context is the Porter hypothesis. It suggests that higher environmental standards can incentivise innovation and, as a result, firms become more competitive. Porter and Linde (1995) described the process by which firms take the environmental regulations into account and evaluate the downside risks posed by their existence. Firms then make plan investments in technological or operational modifications that lead to greater resource productivity. Shao, Hu et al. (2020) suggested the theory's validity depends on the characteristics of the enterprises in question, the mechanisms through which the environmental standards are applied and on the ways in which firms in the industrial ecosystem in which the enterprise was a participant behaved.

The Porter hypothesis is, consequently, important in the consideration of incentives in both construction and demolition waste management as well as the development of steel products with lower environmental impact. It suggests that rather than new regulations that tighten environmental standards being a threat to incumbent industry, they are instead a stimulus for innovation and gains in competitiveness.

If it proved valid in the context of producing steel under greenhouse gas constraints, for example, the Porter hypothesis would counter perceptions about the significance of problems such as carbon leakage (Haywood 2011, Barrett, Peters et al. 2013, Grubb, Jordan et al. 2022). According to Rossetto (2023d p.2) , carbon leakage is said to occur "…*when greenhouse-gas intensive production relocates to jurisdictions with less stringent or no emissions constraint. It can also arise when domestic production is replaced with imports from the less carbon constrained countries*". This is particularly relevant in the context of resource recovery within the construction and demolition waste ecosystem, whereby utilising scrap steel has been shown to contribute to lower greenhouse gas emissions per tonne of steel produced (Rossetto 2023a).

2.6.3 Coase's theory

The final theory of relevance is Coase's theory. This theory concerns itself with the efficiency of market-based incentive mechanisms designed to internalise the costs of negative social and environmental externalities; and is based around the concept of the property rights. Property rights are an important legal entitlement to determine the way a resource is used or deployed, which can also become an important determinant of efficiency (Lai, Ngar Ng et al. 2007, He, Tan et al. 2020). The owner of a property right can either choose to use the resource that is subject to the right, or it can prohibit other parties from using the resource. One of the most common examples is that of land title, over which the owner can restrict access by others.

There are other instances where rights are created by governments and parliaments to carry on specific activities or to emit a certain level of pollution, which is commonly the case in market-based incentive systems (Sandmo 2000, Stavins 2003).

Coase (1960) was interested in whether there was a more efficient way of internalising the costs of harm than Pigouvian taxes or regulations. Coase was in search of solutions that would allow for market-based transactions that lead to higher levels of societal welfare. In the case of taxes, Coase highlighted the scope for taxation revenues collected to be reallocated in ways other than providing compensation to those who suffered. Coase also noted that regulatory provisions to prohibit certain activities simply because they generate harm are inefficient. This is due to the fact that there is economic harm caused as a result of taking action to prohibit the activity, thereby rendering regulation, in principle, a fairly blunt and inflexible instrument. In other words, regulations imply that there is no price at which the harmed parties would feel compensated and therefore be comfortable for the activity to continue. Coase sought to analyse arrangements in which affected parties were able to bargain with each other to find whether such a price existed, in which case the party causing the harm could carry on but paying a true price to internalise the externality.

Coase suggested that the efficiency would be the same regardless of which party were allocated the rights and which, therefore, were obliged to entice the other into a negotiation. One of the fundamental assumptions of Coase's work was that transaction costs were zero (transaction costs could be described as all the costs of counterparty identification, proposal development, negotiation, legal documentation and administration, among others, in giving effect to such bargaining transactions). As much as Coase was lauded, this assumption proved to be an element that was criticised for its failure to take into account real world conditions (Lai, Ngar Ng et al. 2007, Deryugina, Moore et al. 2021, Hervés-Beloso and Moreno-García 2021).

Coase later sought to clarify his intention in assuming zero transaction costs, which was more to draw attention to the fact that modern economics did not – at that stage - have a way of properly acknowledging and taking into account such transaction costs (Coase 1988). To illustrate general concept put forward by Coase, let us take the example of real property and its access to sunlight.

If the owners of a property (Party A) have a right to a certain amount of sunlight – say for the production of electricity using a photovoltaic array – it would be incumbent on any developer who proposed building a new structure adjacent this property (Party B) to negotiate with Party A on an appropriate level of compensation for the right to build in such a way as to obscure this access to light. Party A would have liberty to set the price above the level of the marginal benefit it receives from its access to light. If this price happened to be below the marginal benefit that Party B would derive from building its new adjacent structure, then the basis for a rational transaction between the two self-interested parties would exist. The amount of compensation paid in such a transaction would reveal the cost of the externality associated with blocking access to sunlight and thereby reducing Party A's utility.

From an efficiency perspective, Coase also suggested that the cost of the externality does not depend on which of the two parties were allocated the right. For example, an equally efficient transaction could be negotiated in the case where Party B were given the right to build the new structure. In this case, it would be Party A that could seek to pay Party B to construct a building whose height was limited such that access to sunlight were not blocked.

This situation becomes somewhat more complex if everyone in the street had the same right to sunlight as Party A but were negatively impacted by Party B's development. It would be even more complex again if this applied to the entire suburb. How would Party B organise its negotiations with the multiple other parties? Would all negatively affected parties value the utility foregone in the same way? How would Party B handle such diversity in valuation? What if some parties refused to negotiate at all? The costs associated with organising these matters represent the transaction costs that Coase had originally assumed to be zero.

In other words, it is in these cases, where transaction costs make Coasean bargaining either impossible or too costly, that systems involving property rights have their limitations. It is in these situations where regulatory solutions may be the most efficient (Posner 1986, Calabresi 1991, Deryugina, Moore et al. 2021, Hervés-Beloso and Moreno-García 2021). This does not rebut the theory but rather highlights Coase's point that attention focus on transaction costs.

Notwithstanding, the applicability of Coase's theory was an important one for exploration in this research project. In the case of market-based incentive programs, it is probable that some degree of property right creation. Lai, Ngar Ng et al. (2007), Lu, Chen et al. (2016) and Peng, Lu et al. (2022) have all noted the relevance of Coase's theory to construction and demolition waste applications. Scholars such as Rossetto (2023a), on the other hand, illustrated that allocation of permits within the EU emissions trading system can impact the incentive to recover and utilise more scrap steel. The question of how it impacts the suitability of Coase's Theory for incentives in construction and demolition waste applications therefore remains an important one; and this research has sought to answer it.

2.7 Summary and the knowledge gap

The literature review presented in this chapter, in conjunction with the reviews done in each of the five portfolio papers, has illustrated a gap in the knowledge of what can be done to best incentivise improvements, by private actors, in waste management practices.

Moving beyond regulatory actions that either prohibit certain practices or mandate others, there are gaps in understanding about the most effective economic motivators of action. This has led to the development of the fundamental question: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* There are choices for policy makers that extend between reliance on voluntary action by firms through to the compliance-based incentive programs that can be introduced. Among the latter are revenue support mechanisms, cost-of-capital support mechanisms and negative externality levies, all of which have the potential to trigger innovation and investment by private entities.

The theoretical framework for understanding and assessing effectiveness – and the basis on which this thesis is constructed - is derived through Market-based Management, Coase's theory and the Porter hypothesis. The first of these suggests that the incentive for businesses to secure market share and to be profitable are sufficient motivators, provided that the customer base has a preference toward sustainable and circular waste management practice. Porter's Hypothesis implies that the incentive to innovate will come from compliance with higher environmental standards, with the alternative being a loss of competitiveness. Finally, Coase's Theory implies that property rights, irrespective of how they are first allocated, form the basis of an incentive for negotiations between firms and affected third parties to internalise social costs. Each of these theories, if proven true in a given case, would have implications for the validity of others.

Chapter 3. Research methods

This chapter outlines the methodology undertaken to complete the research presented in this thesis. It introduces the hybrid qualitative and quantitative approach deployed to answer the research question and address each of the objectives. It outlines the sources of data utilised, along with the methods used to validate the research such that it is reliable and avoids bias.

3.1 Approach

The research approach was designed to answer the question: *How can incentives for resource recovery and utilisation in construction and demolition waste sector (specifically focused on steel) be improved?* To answer the question, approaches were designed to address each of the five research objectives as follows and repeated here from the introduction:

Objective 1. Define the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation (levies) and market-measures, that be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices.

Objective 2. Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste.

Objective 3. Examine the long-term feasibility of international measures – in particular border carbon measures – as a means of providing incentives for resource recovery and utilisation in construction and demolition waste practices.

Objective 4. Assess the effectiveness of voluntary action by firms to address externalities generated within the construction and demolition waste ecosystem.

Objective 5. Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management.

The scope of the project was limited to focus on steel, given its materiality within the construction sector, its status an emissions intensive and trade exposed industry and the scope to recover and utilise waste material (Kyriakopoulos 2021, Prasad, Sakura et al. 2022, Rossetto 2023a).

The research was designed to include *deductive* techniques for determining the applicability of existing theories as well as *inductive* techniques to develop new theories (Armat, Assarroudi et al. 2018, Woiceshyn and Daellenbach 2018). A number of quantitative and qualitative methods were considered for the research project, which are explained in more detail below.

3.2 Quantitative methods

Williams (2011) outlined a number of options available for quantitative research, including (1) descriptive techniques, (2) experimental methods and (3) causal comparative analysis. Descriptive techniques involve analysing current state of a given phenomenon, identifying its attributes on an observational basis and then making extrapolations based on future scenarios. Experimental methods model the performance of specific interventions through simulation and causal comparative analysis examines how dependent variables are impacted by independent conditions.

Resource recovery and utilisation in the area of steel production is already happening, suggesting that some historical information about the practice area already exists. This would allow for what Ployhart and Vandenberg (2010) call *longitudinal or cross-sectional analysis* to be deployed, which are descriptive backward looking studies of contemporary events that identify salient variables and correlations. Bendor, Eriksson et al. (2021) described this as past-casting, whereby information about the past allows researchers to identify potential symmetries with the future. While longitudinal and cross-sectional analyses are backward looking, they are based on contemporary events.

There are also some limitations associated with the use of forward-looking simulations. Parker (2020) found that evidence from simulation is useful but it is different from evidence from observation and experiment. Simulations generally help develop the predictive basis for research but themselves do not generate new knowledge about real world phenomena. In some cases where other data are not available, simulation may be necessary, though it is not the case for this research project. All of this adds some weight to the choice of descriptive techniques for deployment within the context of this research.

3.3 Qualitative methods

Qualitative methods can be used to develop indicators of human practices in such a way as to make them more understandable, predictable and traceable (Saldaña 2021). Within qualitative methods, there are five broad categories available for researchers, which include experiments, surveys, archival analysis, histories and case studies. Yin (2009) provided an overview of when and how to use each one of these methods, which is summarised in Table 2 below.

Table 2 - Relevant situations for different qualitative research methods

Method	Form of research question	Requires control of behavioural events?	Focuses on contemporary events
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival analysis	Who, what, where, how many, how much?	No	Yes/no
History	How, why?	No	No
Case study	How, why?	No	Yes

Source: Based on Yin (2009)

Qualitative researchers also have choices about the ways in which qualitative materials emanating from these methods can be analysed. Saldaña (2021) used the term coding to describe the way that qualitative information can be organised for further analysis. These are broad thematic headings that help to identify patterns within the roles and relationships that the qualitative data contains. Yin (2018) suggested that it was important to identify the units of analysis, whereupon the coding can be applied to extract any patters of relevance to the research question posed. Bernard (2018) described coding as a method for linking qualitative information collected from single units, groups, organisations or events.

While it is possible to use qualitative methods independently of quantitative in social sciences research, scholars such as King, Keohane et al. (1994) and later Maggetti, Gilardi et al. (2013) highlighted that it is possible to adopt hybrid approaches. Hybrid approaches, where it is possible to use them, can allow for validation of qualitative results and vice versa, increasing the reliability of the research conclusions.

3.4 Managing researcher subjectivity and bias

The research presented in this thesis was a study of complex processes connected to commercial practice as well as applications of theory, with a range of quantitative and qualitative tools available to achieve the objectives. The complex interactions inevitably imply there will be some elements of judgement, particularly when those elements involve determining the *most effective* solutions, or indeed what constitutes an *incentive*. Flick and Metzler (2014) noted that it is possible for judgement to be exercised within this kind of research, though there will be a degree of subjectivity involved. Subjectivity is likely to arise depending on the researcher's perspective, experience and social background. Rather than seek to exclude subjectivity altogether, the authors recommended acknowledging and controlling it rather than its elimination.

The author of this thesis is an experienced finance and risk management practitioner in the private sector with over 20 years of experience gained working across five different continents in both OECD and developing country context. The author also spent over six years as a policy maker and has been a senior executive in two multinational companies. While this experience serves as a helpful basis on which to design the research and analyse information, it does introduce the risk of bias. A number of safeguards are available to reduce instances of or the potential impact of any bias, including:

- In the case of subject matter with which the researcher is familiar, adopt the thesis by portfolio of publications approach. A portfolio of publications means that the thesis is presented with a number of papers either submitted, published or accepted for publication in recognised academic journals. Carried out in this way, the findings are the subject of peer review.
- In the case of any involvement of human subjects in qualitative components of the research, seek to involve participants who were not previously known to the researcher and where no conflict of interest exists.

3.5 Selected methods

As it was introduced in Section 3.1 of this chapter, the research methods deployed for this thesis were tailored to each specific research objective. In the case of objectives two through to five, a stand-alone paper is presented to address each of these. There was no separate paper prepared to address objective one. Accordingly, the specific methods selected to address each objective are presented below:

*Define the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation and market-measures that can be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices (**Objective 1**).*

The primary method for answering this research objective was qualitative. The starting point was to consider the spectrum of incentives that emerge from literature, not just related to construction and demolition waste or steel, but also the broader disciplines of welfare economics and the economic analysis of law.

In order to increase the reliability of the literature review findings, a series of practitioner interviews were undertaken with participants employed in organisations within the construction and demolition waste ecosystem. The practitioner interviews were limited to participants based in Australia, which was necessary in order to meet the conditions of approval provide by The University of Adelaide's Human Research Ethics Committee (HREC). The findings of these interviews are contained in Chapter 4 (Practitioner interviews). The participants and their organisations therefore became the units of analysis within this qualitative research component.

Participants were selected on the basis that they were in senior- or middle-management positions within organisations in the construction and demolition waste ecosystem and participant in the green steel market. In order to capture a representative cross-section of entities within the ecosystem and the functional areas, five different categories of organisation were developed.

The profiles of these organisations – and the category to which they are assigned – are listed below:

- Organisations operating sites that generate construction waste, including prefabrication and off-site assembly for construction projects (***Category 1***).
- Organisations involved in receiving, sorting and processing waste and preparing it for sale to materials manufacturer(s) (***Category 2***).
- Organisations manufacturing materials that either already do, or could in future, utilise recycled construction and demolition waste and waste from other sources (***Category 3***).
- Organisations advising on, specifying or using materials that either already do, or could in future, utilise recycled waste from the built environment and other sources within a project context (***Category 4***)
- Public agencies that develop and implement regional, national and international policy, legislation and regulations for the construction and demolition waste ecosystem (***Category 5***).

The full spread of participating practitioners is provided in Table 3 below.

Table 3 - Units of analysis

Participant code	Description	Category	Functional area[2]
Participant 01	Resource recovery and remanufacturing firm	2	5 & 6
Participant 02	Provider of materials, products, systems and technologies	1 & 3	2 & 4
Participant 03	Provider of materials, products, systems and technologies	1 & 3	1, 2 & 3
Participant 04	Technical design and advisory services firm in the private sector	4	4 & 5
Participant 05	Client organisation also involved in policy making	4 & 5	4 & 5
Participant 06	Public policy agency	5	1-6

[2] Functional areas are described in portfolio paper three in Chapter 7 (Figure 2).

Interview protocols were developed and eventually gained approval from the HREC on 12 May 2021 (approval number H-2021-069). These protocols were designed to be open in order to invite the thoughts of each participant and stimulate discussion. This is quite different from a survey approach, in which very specific questions are posed in order to constrain the answers to topics that a researcher wishes to analyse post-interview. The protocol questions for each case area are provided below in Table 4. Formal minutes were agreed with each participant based on follow-up circulation of drafts and subsequent discussions. The interviews were carried out during the second half of 2021 and follow-up occurred during 2022.

Table 4 – Interview protocol questions

Number	Question
1	What is your main interest in construction and demolition waste and why do you believe it is important?
2	What do you consider to be the most important advantages and disadvantages of your organisation's approach to construction and demolition waste management?
3	Are there any improvements that you would like to suggest, whether they be voluntary, regulatory or other?

Following completion of the interviews, qualitative analysis was undertaken. Units of observation were developed to correspond with the sub-headings of the literature review (refer Sections 2.4.1 to 2.4.6), which formed the basis of the identification of patterns across the interviewees. These units of observation are provided below in Table 5.

Table 5 – Units of observation

Unit code	Description
01	Voluntary
02	Taxation and subsidy
03	Public investment
04	Regulation
05	Common law
06	Market-based

It has been highlighted by a number of scholars that validating and triangulating qualitative information collected during empirical research is of importance to the integrity of the conclusions eventually drawn (Yin 2009, Flick and Metzler 2014, Yin 2018).

Given the political, commercial (being trade secrets and competitive advantage) and other interests implicit with those practitioners interviewed, the researcher developed safeguard reviews to (a) take account of possible participant biases that may have come through from the interviews and (b) make allowance for some incomplete information given that not all relevant information is possible to disclose. In addition to the interviews, therefore, this analysis is deployed as a means of complimenting and validating the information obtained.

The other safeguard used is that of triangulation. This is achieved by having a minimum of three organisations within each of the three case areas. Triangulation involves collecting information covering similar topics from at least three sources, which allows the researcher to compare and contrast the information received. The results of the practitioner interviews, which are presented in Chapter 4 therefore serve as a basis to verify the validity of the literature review findings.

*Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste (**Objective 2**).*

As foreshadowed in the preamble to this section, objective two was addressed via a stand-alone paper, which is called *The carbon border adjustment mechanism: What does it mean for steel recycling?* It was published in the Sustainable Horizons journal in March 2023. Its aim was to explore whether the European Union's proposed carbon border adjustment mechanism (CBAM) program, which is designed as a market-based measure for greenhouse gas abatement, is likely to drive demand for resource recovery and recycling. While CBAM is designed to cover six different product areas, the focus of this study was limited to steel products, which aligns with the scope of this thesis. It sought to answer the research question: *Will CBAM create an incentive for greenhouse gas reduction and resource recovery in steel production?* As the measure had not yet legislated and become operational, the research question was informed by longitudinal analysis and addressed using *logic* and *explorative* methods.

The study first applied *logic* to determine whether the introduction of CBAM, coupled with the removal of free allocation of European allowances to domestic producers, will lead to an incentive for greenhouse gas reduction. This is, in effect, an investigation into whether new environmental regulation can lead to corporate innovation and an eventual increase in competitiveness. The next step was to *explore* whether using scrap steel as a feedstock material represents a genuine abatement measure available to both the entities being covered by CBAM and those domestic (EU-based) steelmakers that would no longer have access to future free allocations under the EU ETS once CBAM is introduced. The study achieved this by considering the performance of different steelmaking techniques, using a combination of default values and plant specific energy emissions factors, applied to historical spot emissions price (the market for EUAs that is for immediate rather than future delivery) observed in the EU ETS over a six month period.

Finally, the study examined the relationship between EU carbon prices, scrap steel and finished steel over the same six month period to examine whether there is any evidence that free allocation is indeed muting the price signal to recycle as had been suggested by Sandbag (2022). If this were validated, it would support the idea that CBAM will generate an incentive for abatement as removal of free allocation of EUAs remains part of the mechanism's design.

Examine the long-term feasibility of international measures – in particular border carbon measures – as a means of providing incentives for resource recovery and utilisation in construction and demolition waste practices (***Objective 3***).

Objective three was addressed via a stand-alone paper entitled *The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the EU and the United States and the steel production sector* and was published in the Sustainable Horizons journal in June 2023. Its methodology was designed to address two research questions about border carbon mechanisms, as follows:

1. How significant is the problem of carbon leakage in the area of steel in the European Union and United States that would warrant action on border carbon mechanisms?
2. What are the specific areas in which such programs are vulnerable to challenge?

The research used a deductive approach, testing the validity of the US and EU cases with the *Porter Hypothesis*, which suggests that environmental regulation drives innovation within firms (Porter and Linde 1995, Shao, Hu et al. 2020). Theories of carbon leakage suggest the opposite of the Porter Hypothesis. That is, under carbon leakage, one would expect to observe migration of production to the region(s) with less stringent regulation rather than innovation.

To answer the first question, quantitative longitudinal analysis was deployed to evaluate key trends and patterns in greenhouse gas emissions and steel production data in both the EU and US covering a decade (calendar years from 2012-21 inclusive).

The analysis explored two specific indicators. The first related to changes in the greenhouse gas intensity of steel production per tonne over the time period. The second considered the degree of change in import reliance over the period, which was measured as the net imports (imports minus imports of tonnes of finished steel) as a percentage of *apparent* consumption of steel. The analysis tracked sector-wide advancements made in both the EU and US toward decarbonisation of steel to verify the magnitude of efforts being made. It also considered the extent to which the US and EU are becoming more (or less) reliant on imports in order to meet demand for steel in the respective economies.

The study addressed the need for further empirical work to be done to validate the possible leakage effects identified by Eskander and Fankhauser (2023) and considered the applicability of the Porter Hypothesis.

In order to answer the second question, qualitative analysis provided a basis for assessing the border carbon mechanism approaches – combined with the domestic approaches where appropriate - being used by both the US and EU against the critical criteria identified in the literature review that would otherwise make them vulnerable to challenge. The criteria were developed based on the themes of environmental integrity, WTO consistency, UNFCCC consistency and sovereignty impact, as follows:

- *Environmental integrity*: Encompassing consideration of whether the approach is likely to reduce emissions. For example, does it have the potential to reverse an existing trend or remove a known impediment to abatement in the steel sector?
- *WTO consistency*: Including whether there is evidence that the measure is likely to levels the playing field, meaning that emissions constraints or production incentives linked to abatement will be demonstrably similar in all relevant countries;
- *UNFCCC consistency*: Covering whether there is evidence the measure addresses or is consistent with common but differentiated responsibility;
- *Sovereignty*: Considering whether the measure avoids impacting one or more trading partners' sovereignty, being the right of a nation state to determine the laws and regulations on its territory and not have them decided upon by another entity.

A scoring system was used to allocate a maximum of one point for each criterion. Scores closer to four would therefore mean the measure is more sustainable in the longer term, whereas scores closer to zero would indicate a higher level of risk. This component of the study informed the deductive investigation of the validity of Porter's Hypothesis, as innovation in corporate response is connected not only to the presence of environmental regulation but also its perceived sustainability.

Assess the effectiveness of voluntary action by firms to address externalities generated in the construction and demolition waste ecosystem (***Objective 4***).

Objective four was addressed via a stand-alone paper entitled *Relationships between sustainability disclosure, environmental innovation and performance: An examination of practice within the Australian construction and demolition waste sector* and was published in the Environment, Development and Sustainability journal in December 2023.

The aim of the study was to investigate the extent to which voluntary corporate action is contributing to the identification, reporting, disclosure and management of externalities within the Australian construction and demolition waste ecosystem. It considers these issues in the context of case studies that examine businesses within the functional areas of the Australian construction and demolition waste ecosystem. It notes patterns about the current state of the ecosystem in response to the research question: To what extent is voluntary action becoming sufficient to address externalities generated by the construction and demolition waste ecosystem?

Two different empirical approaches were designed for application to the case studies: interviews and analysis. Interviews were chosen in order to solicit opinions on topics raised in scholarly research and validate these as relevant for practice. Analysis was chosen in order to objectively establish current practice on reporting. Organisations were chosen to participate so that all of the functional areas of the ecosystem, being (1) raw material feedstocks and inputs, (2) manufacturing, (3) construction and demolition activity, (4) waste management (5) imports and exports, were covered.

Interviews were deployed as a basis for soliciting the views of individual executives, in their capacity as agents of organisations that are active participants in the extended ecosystem in or connected to Australia. The purpose of the qualitative research is to identify the extent to which voluntary solutions to deal with externalities within the ecosystem are being explored or implemented by organisations active within the ecosystem; and to seek support for the sustainability-related items being reported by those organisations. The analysis was designed to examine the annual reports and other corporate documents issued by the participating organisations on a systematic according to four main categories of data item as summarised in Table 6 below.

This includes the standards applied or used in determining the extent of reporting and disclosure, a non-comprehensive set of areas where externalities might be expected and whether there is any reporting of contingent liabilities or assets (an asset would apply in cases where the externality were positive).

Table 6 – Summary of data items reviewed in company documentation as part of the analysis

Data item	Description
Standards	Has a standard been used for determining the data to disclose – in particular the Global Reporting Initiative, the Sustainability Accounting Standards Board and the Taskforce on Climate-Related Financial Disclosure, which may be indicators of how it applies materiality?
Externalities (negative)	Is there evidence of some form of disclosure of environmental indicators by the organisation that may be linked to negative externalities such as air pollution, water use and pollution, material consumption and greenhouse gas emissions across scopes one, two and three?
Externalities (positive)	Is the organisation disclosing information about its recycling or resource recovery rates?
Contingencies	Is there any evidence that externalities are appearing as contingent liabilities (or assets in cases where the externalities were positive), which indicates a potential future impact on the organisation's financial performance?

Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management (***Objective 5***).

Objective five was addressed via the paper entitled *The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia* published in the Carbon Neutrality journal in September 2023.

To respond to this objective, two questions were formulated as follows: (1) How extensively are waste sector abatement opportunities represented so far within those that have generated Australian Carbon Credit Units (ACCU)? (2) What is the capitalised contribution to equity returns of ACCU revenues over a project's crediting period?

To answer the first question, longitudinal analysis was used to examine projects registered under the Australian Carbon Credit (Carbon Farming) Act 2011 over the 10-year period covering the financial years 2012-13 to 2021-22 to determine the relative share of waste projects in generating ACCUs and the contributions made by projects using different waste methods. Waste methods used were then compared with the potential for resource recovery and other abatement projects at higher stages in the waste hierarchy to determine the extent to which project deployed to date are comprehensive.

To answer the second question, a financial model was used to examine the impact of ACCU revenues on project equity returns under different scenarios that tested sensitivities of two separate theoretical projects – ***Project one*** being a 2MW biogas cogeneration plant and ***Project two*** being a 30MW energy from waste project - under different ACCU price levels and in different states of Australia connected to the National Electricity Market (NEM) using average wholesale electricity prices across those states based on the outcomes in the 2020/21 and 2021/22 financial years, renewable energy certificate price levels, loan to value ratios and terms of debt financing. The projects were selected to represent the two main methods of producing energy from organic waste: anaerobic decomposition and incineration.

3.6 Data collection and analysis

As this thesis is a portfolio of publications and each paper has its own explanation of the data collection and analysis techniques used, this sub-section provides a summary for the entire thesis. Further detail to support this summary can be obtained by reviewing each portfolio paper and the practitioner interviews, which are located in the referenced chapters (4-9).

Table 7 – Summary of data collection and analysis used across the portfolio of papers

Research objective	Paper and chapter number	Methods used	Data sources
1	Practitioner interviews (Chapter 4)	Qualitative analysis through interviews.	The author's own interviews and data.
2	Paper one (Chapter 5)	Qualitative logic and quantitative analysis using correlation studies.	Commodity data from the European Energy Exchange and London Metal Exchange.
3	Paper two (Chapter 6)	Quantitative longitudinal analysis on import dependence and emissions intensity.	Trade emissions data from the US government, European Commission and Eurofer.
4	Paper three (Chapter 7)	Qualitative analysis through interviews and quantitative analysis using company financial data.	The author's own interviews and data and financial and non-financial information in company reports.
5	Paper four (Chapter 8)	Quantitative analysis using a purpose built financial model and sensitivities.	Data from the Australian government (Clean Energy Regulator), Australian Energy Market Operator.
General	Paper five (Chapter 9)	Quantitative analysis using a purpose built financial model and sensitivities.	Financial data from the European Central Bank and the OECD, with project data from various sources.

3.7 Summary

The preceding sections describe the different quantitative and qualitative research techniques available to respond to the research question: *How can incentives for resource recovery and utilisation in construction and demolition waste sector (specifically focused on steel) be improved?* There are many examples where both property rights-based systems and environmental standard-raising through regulation either have been applied or could be applied to solve challenges in construction and demolition waste management; and indeed with steel. Therefore, research methods deployed for this thesis were tailored to each specific research objective as was outlined in Chapter 3. In the case of objectives two through to five, a stand-alone paper is presented to address each of these. There was no separate paper prepared to address objective one. Rather, the practitioner interviews served as an empirical and quantitative means of validating the relevance of the forms of incentive that were identified in Section 2.4 of the literature review.

As previously raised in the introduction, the research undertaken as part of this thesis is subject to the following limitations:

i. There are many different materials used in construction and equally different feedstocks used in their production. In order to focus the research, it considers steel in great detail. While steel is an important construction material and worthy of detailed consideration, it there are potential differences with others like aluminium, plasterboard, cement, among others, which this research does not cover.
ii. It is focused on economic incentives as the motivators for change. There are other kinds of incentives, which include regulatory actions to prohibit certain actions or to mandate others, as well as other factors that affect decision-making such as ethics. These are outside the scope of this research project and therefore serve as an important limitation.
iii. It does not analyse the forces that bring about the incentives via public intervention in markets, which might be explainable using theories of the political economy and public choice.

Chapter 4. Practitioner interviews

The following chapter presents a synthesis of the results of the practitioner interviews. A description of how the participants were chosen, the organisation each participant represents and the interview questions had previously been described in Chapter 3 (Selected methods, refer to objective one). The full-form proceedings of the interviews are provided in Appendix B.

The practitioner interviews were deployed solely as a means of validating the relevance of the incentive mechanisms outlined in Section 2.4 of the literature review for the specific context of construction and demolition waste and resource recovery in Australia. While the sample of six participants, this is partly a reflection of the limited size of the Australian construction and demolition waste ecosystem itself, which turns over marginally less than AUD $5 billion per year (Thomson 2021).

The practitioner interviews therefore provide an important empirical function in addressing the first research objective, namely: *Defining the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation and market-measures, that be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices*.

4.1 Voluntary action

Voluntary action is, in effect, the scenario most aligned to the Market-Based Management theory. It represents the situation in which markets have the least amount of intervention and suppliers of products and services are driven by consumer preferences. The marketplace therefore offers incentives to supply products and services at levels of quality, quantities and prices that meet those consumer preferences.

The interviewees shared a number of important considerations for voluntary action. In some cases, customers and groups of customers are driving change by requiring that their suppliers address waste management issues within products and approaches. There are also some instances in which the marketplace appears to be moving in a given direction in the long-term. In such cases, investments today are made at least in part on the expectation that this is going to occur. Finally, there are some areas in which participants felt as though some activities were voluntary, though in reality they are driven by a regulation or other rule, where participants were not immediately aware.

4.2 Taxation and subsidy

Taxation and subsidy programs arise in situations where policy makers seek to utilise the forces of price equilibrium to dissuade consumption of products and services that generate negative externalities by taxing them or encourage those activities that generate positive externalities by subsidising them.

Interview participants frequently referred to landfill levies as being similar to taxes, in that they were a form of negative externality levy. This kind of measure provides an incentive for some action. One participant referred to a government agency which administers grants – as a cost-of-capital support program that is directly funded through the proceeds of landfill charges. Not all were convinced, however, that this was the ideal form of incentive. In fact, some participants that shared details of developing life-cycle costing approaches to materials procurement, which would sometimes allow more expensive solutions to be chosen due to the long-term benefit.

4.3 Regulation

Regulation is common within the Australian construction and demolition waste ecosystem. In principle, there are broad guidelines for public policy makers in Australia that suggest regulation be used, in general, when the transaction costs of different solutions are prohibitive (Council of Australian Governments 2007). In such cases, regulations that either prohibit certain practices or mandate others are deployed. In some cases, the existence of regulations in other areas create spill-over effects that incentivise resource recovery.

A number of participants felt like regulation was the only solution to certain very difficult problems. However, this was not always that certain activities be banned or others be mandated, but rather there needs to be a polluter pays principle. In this respect, regulation could be used to establish the imperative that negative externalities be internalised. This provides a different perspective on how a regulatory solution could function as an economic incentive.

4.4 Common law

While the most obvious regulations that apply to construction and demolition waste activity in Australia are derived via deliberate action by lawmaking bodies like the parliaments at state and national level, common law also provides a degree of impact on the incentives relating to certain activities.

Common law was seldom mentioned in the interviews, though there were details shared in which part of the justification of new incentives was the need to avoid legal disputes. In other words, policymakers believed that society as a whole would be better off as a result of new incentive programs rather than letting each market participant be driven by precedents at common law.

4.5 Market-based programs

Construction and demolition waste affords some opportunity to harness market forces through the deployment of market-based programs. Other programs, particularly those linked to the positive externality of reduction of greenhouse gas emissions, can also impact the level of resource recovery occurring across the construction and demolition and other sectors.

It was commonly acknowledged by participants that the economics of certain activities is constrained by the inability of firms to be compensated for the generation of positive externalities. Several participants spoke about the need for border carbon adjustments as a means of providing a market-based solution to deal with industrial competitiveness impacts in internationally traded building products like steel, cement and aluminium. In this respect, there was a recognition that greenhouse gas reduction benefits and markets to encourage them could result in resource recovery co-benefits.

4.6 Summary

The purpose of the practitioner interviews was to validate the relevance of the incentive mechanisms outlined in Sections 2.4 and 2.5 of the literature review for the specific context of construction and demolition waste and resource recovery in Australia. The practitioner interviews have illustrated that there are many examples of the full spectrum of incentives - including voluntary action, common law, subsidies, regulation, taxation and market-measures – either already in use or considered desirable in future to incentivise resource recovery and utilisation in construction and demolition waste practices. In some cases, interview participants described what appeared to them to voluntary activities that were, in fact, arising due to regulations in other sectors. Participants also discussed current and future programs, which can also impact the level of resource recovery occurring across the construction and demolition and other sectors. This was particularly so for programs linked to the positive externality of reduction of greenhouse gas emissions, such as carbon markets.

Chapter 5. Publication one and statement of authorship

This section presents the publication: *The Carbon Border Adjustment Mechanism: What does it mean for steel recycling?*

5.1 Statement of authorship

The statement of authorship is provided below in Table 8.

Table 8 – Statement of authorship for publication one

Title of paper:	**The Carbon Border Adjustment Mechanism: What does it mean for steel recycling?**			
Publication status:	Published	×	Accepted for publication	
	Submitted for publication		Unpublished and unsubmitted work written in manuscript style	
Publication details:	Rossetto, Daniel. (2023). "The carbon border adjustment mechanism: What does it mean for steel recycling?" Sustainable Horizons **5**: 100048. DOI: https://doi.org/10.1016/j.horiz.2023.100048 Reproduced in accordance with the publishing agreement.			
Name of principal author:	Daniel Marc Rossetto			
Contribution to the paper:	Research design, research execution and sole author			
Overall percentage:	100%			
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.			
Signature:				
Date:	14/03/2024			

5.2 Specific aims of the paper

The aim of this study was to explore whether the European Union's (EU) proposed Carbon Border Adjustment Mechanism (CBAM) program is likely to drive demand for resource recovery and recycling. CBAM, a mechanism named on a number of occasions during the practitioner interviews (details of which are contained in Chapter 4) is designed to operate in support of the EU's emissions trading system (ETS), which is a market-based measure that seeks to reduce greenhouse gas emissions. The EU ETS and CBAM programs therefore have, collectively, the characteristics of both revenue support and negative externality levy programs.

It addresses the research project's second objective, as articulated in the introduction, which is to: *Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste*.

While CBAM, as it has been proposed by the European Commission, covers six different product areas (steel, aluminium, cement, fertilisers, electricity and hydrogen), the focus of the paper was limited to steel products to align to the scope of this doctoral research project. In doing so, it sought to respond to a focused research question: *Will CBAM create an incentive for greenhouse gas reduction and resource recovery in steel production?* In doing so, it deals with the doctoral research project's second objective, which is to: *Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste*.

The paper is significant in that it highlights the importance that free allocation of property rights can have on the incentive that firms have to respond to a price signal created by a market-based system; in this case the use of scrap steel. This adds considerable new insight into theories of economic welfare including but not limited to Coase's theory, which would have otherwise led to the conclusion that initial allocation of property rights were not significant.

5.3 Current citations

The paper has been cited, thus far, in the following subsequent publications:

Zhou, W., et al. (2023). "The robustness and disturbance within China's industrial complex network under carbon border tariffs." Environmental science and pollution research international 30(50): 109841-109853.

Li, W., et al. (2023). "Analysis of China's steel response ways to EU CBAM policy based on embodied carbon intensity prediction." Energy. Vol. 282, 1 November 2023, 128812.

Sun, W., et al. (2023). "Coastline extraction using remote sensing: a review." GIScience and remote sensing. Vol. 60(1).

Whelan, D. (2023), "Accelerating the transition to a circular economy (CE) through exchange of excess materials: A conceptual framework for an excess materials exchange (EME) for the public sector, built environment in Ireland". Thesis submitted to the Atlantic Technological University, Sligo.

Rossetto, D. (2023). "The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector." Sustainable Horizons. Vol. 6: 100053.

Rossetto, D. (2023). "The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia." Springer Nature Carbon Neutrality Volume 2(Issue 2).

5.4 Publication one

The paper as published in March 2023 is now included.

Sustainable Horizons 5 (2023) 100048

Contents lists available at ScienceDirect

Sustainable Horizons

journal homepage: www.elsevier.com/locate/horiz

The carbon border adjustment mechanism: What does it mean for steel recycling?

Daniel Rossetto

School of Architecture and Civil Engineering, The University of Adelaide, Faculty of Sciences, Engineering and Technology, Australia

ARTICLE INFO

Keywords:
Emissions trading
Electric arc furnace
Scrap steel
Carbon border adjustment mechanism
Embodied energy
Circular economy

ABSTRACT

The European Union's carbon border adjustment mechanism (CBAM) is a landmark policy proposal. As this study finds, not only might it assist in providing signals to lower emissions in some of the most greenhouse gas-intensive sectors of the world economy; it also may also drive resource recovery.

This study focuses on CBAM's impact on scrap use for steel production. It investigates the nature and magnitude of the price signal by analysing costs of compliance for steelmakers using a variety of emissions intensities of different commercially operational steelmaking techniques, applied using the proposed CBAM liability model and emissions pricing data from the clearing prices observed in the EU's emissions trading system (EU ETS). In addition, it examines historical correlations in key commodities linked to steelmaking like EU carbon allowances, steel and ferrous scrap steel, validating the observation made by some analysts that free allocation in the EU ETS mutes the incentive to recycle steel. The study identifies factors that influence the magnitude and nature of the price signal, including uncertainty about the final CBAM design, the impact of market fundamentals and feedstock commodities, alternative green steel technologies and the relative importance of the longer-term outlook compared to nearer-term market signals.

The study finds that resource recovery and recycling will lead to reductions in greenhouse gas emissions and vice versa, meaning well designed measures can advance both aims. This has implications for policy makers and business managers, who will be able to focus scarce resources to capture these co-benefits. This can reduce regulatory burden in an environment where overregulation is identified by previous studies as a barrier to better waste management practice.

1. Introduction and literature review

The European Commission (Commission) launched a Green Deal program in December 2019, which is an umbrella framework for environmentally orientated targets and instruments . It includes a range of policy actions on climate change, among which are proposals to reform the European Union emissions trading system (EU ETS) and the introduction of a carbon border adjustment mechanism (CBAM). It also details a plan to make the EU a circular economy, which encompasses both a Circular Economy Action Plan and a Sustainable Products Policy (European Union, 2003, 2015; European Commission, 2019).

According to the Commission (2021) and (2022a), the purpose of CBAM is to create an incentive for reductions in greenhouse gas emissions within the European Union (EU) and globally connected to production of goods imported into and consumed within the single market in six specific product areas: (1) iron & steel, (2) electricity, (3) fertilisers, (4) aluminium, (5) cement and (6) hydrogen. Another aim of CBAM is to manage the risk that EU-based manufacturers shift production outside the EU on account of differences in carbon constraints in other countries, which is known as carbon leakage. Domestic producers of iron & steel, electricity, aluminium and cement have been, since 2005, required to comply with the EU emissions trading system (EU ETS). Prior to CBAM, carbon leakage risks have been managed by allocating tradeable allowances under the EU ETS to plants that produce those goods at no cost (a practice referred to as free allocation). CBAM will seek to achieve its goals by requiring importers of specified goods to pay for certificates, which will be purchasable from EU member states.

The quantity of certificates needed will be determined according to the embedded emissions associated with their production. According to the European Commission (2022a), importers may also be required to report on indirect (scope two) emissions at the conclusion of the CBAM transitional phase (a three year period beginning in October 2023), such as those resulting from electricity use in addition to the direct emissions. The notion of including indirect emissions would serve to replicate the

E-mail address: daniel.rossetto@adelaide.edu.au.

https://doi.org/10.1016/j.horiz.2023.100048
Received 2 December 2022; Received in revised form 11 January 2023; Accepted 24 January 2023

impact that electricity consumers face in Europe, who purchase on a carbon inclusive basis as electricity generation is a sector covered by the EU ETS (noting also that including electricity generation itself as one of the six products covered by CBAM is designed to address imports from generators based outside the EU in neighbouring countries). Free allocation of permits to domestic producers will be phased out as CBAM is introduced. This step is important as some analysts observe that free allocations mute incentives to abate emissions in industries that receive them (Sandbag, 2022).

CBAM has faced some criticism. Gore (2021) suggested that the program fails to adequately address equity concerns between developed and developing countries. Zhong and Pei (2022) noted the potential for CBAM to have an income redistribution impact at both the sector and national levels. A number of authors, including Qi et al. (2022), Bashmakov (2022) and Urazgaliev et al. (2021), noted potential changes in the competitiveness of producers in countries outside the EU such as China and the Russian Federation if the CBAM is eventually implemented. Starita (2021) argued that the European aluminium industry would remain at risk of carbon leakage notwithstanding CBAM. The European Chamber of Commerce Taiwan (2022) identified several areas of uncertainty – including the methodologies for calculating embedded emissions - that prevent full analysis of CBAM's impacts for businesses located in countries outside the EU.

The concept of countries applying charges at national borders according to the embedded greenhouse gas emissions of products is not new and indeed there have been numerous analyses of such policy approaches undertaken over the last 10-15 years since they were first mooted by governments. Gros (2009), Horn and Sapir (2013), Cosbey et al. (2020) and Bellora and Fontagné (2022) have all considered the consistency of carbon border measures with broader climate and trade policy, concluding that such measures are complex and require much attention. This is because international trade itself is administered through the World Trade Organisation (WTO) and any measures must be compatible with the rules and norms ascribed under the various international agreements that have been made, such as the General Agreement on Tariffs and Trade (GATT). Abnett (2020) reported that it is the European Commission's intention to design CBAM in a manner that is consistent with WTO rules and norms.

This is where the CBAM becomes complex, as it is designed to operate in parallel with the EU ETS as will be described in Section 1.3. Until CBAM is introduced, as has been shown, industries 'at risk of carbon leakage' have been and will continue to be provided free allocations EUAs (largely on the basis of product benchmarks, which is designed to expose qualifying producers to only a partial shortfall in allocations). Therefore, as has been acknowledged by the European Commission (2021), CBAM will need to remove the free allocation system for the products currently receiving that kind of protection. An appropriate pricing level for the importers to pay that does not confer an advantage for the domestic producers will also need to be developed.

Despite the complexity, CBAM is a particularly interesting and important new area of endeavour that spans the intersection of climate policy and the circular economy. Given CBAM's focus on product areas commonly used in construction like iron and steel, aluminium and cement, there is potential for overlap between it, the Circular Economy Action Plan and the future Sustainable Products Policy. Organisations such as the World Steel Association Çiftçi (2022) and Evraz (2016), for example, have noted that using scrap steel as a replacement feedstock leads to production of new primary steel with lower greenhouse gas emissions per unit. Authors such has Prasad et al. (2022) have also noted the potential for circular economic measures to assist organisations with reductions in scope three greenhouse gas emissions, being those that arise in or as a consequence of supply chains.

What is less understood is whether there is any potential for the reverse to apply: That is, where climate policy and measures become the driver of circular economic outcomes. If this proved to be a valid relationship, it would be significant for several reasons. First of all, it would allow policy makers to rationalise the number of measures with which businesses need to comply. Secondly, business managers could focus attention on priority projects, increasing the likelihood of implementation.

This leads to the formulation of two issues that emerge in the context of the EU Green Deal, its joint focus on the circular economy and its links to the CBAM:

> *Issue 1. Carbon border measures represent a more effective way to reduce the effects of carbon leakage for incumbent producers than free allocation of emissions certificates, particularly due to the broadening of the incentive to abate such measures can deliver.*

> *Issue 2. Circular economic solutions such as resource recovery and recycling will lead to reductions in greenhouse gas emissions and vice versa, therefore an opportunity exists to use the same policy measures to advance both aims.*

Accordingly, this paper presents the results of explorative research that considers what CBAM's likely impact will be on recycling through the specific steel industry lens. It does so by posing the research question: Will CBAM create an incentive for resource recovery and recycling in steel production?

The following sections review the literature related to the aforementioned issues. The literature review's scope includes trade and practice literature as well as scholarly literature. This is because CBAM is a relatively new mechanism, where trade and practice literature of relevance is being produced at pace and volume (White House, 2021; Çiftçi, 2022; Sandbag, 2022). Scholarly literature was searched on databases such as Google Scholar using keywords such as 'global steel industry', 'scrap steel', 'steel trade', 'EU emissions trading system', 'CBAM', 'carbon border taxes', 'embedded energy', 'embedded energy' and 'circular economy'. Industry literature was identified using other, non-academic search engines using the same key words, as well as other financial markets and trade media sources such as Bloomberg and Reuters.

1.1. Global steel industry

Steel and its derivative products are internationally traded commodities. According to the World Steel Association (2022), as much as 1.95 billion tonnes of steel was produced across the world during the calendar year 2021. Manufacturers of steel in the EU produced 7.8% of this steel as shown in Fig. 1, making the region the second largest in the world behind China. While the rest of Asia (excluding China) produced 14.2%, India was the largest single country within that total at 6.1%. The EU's share as a percentage of global steel production has been falling in the last 10-15 years, while at the same time the magnitude of its imports has been growing.

According to the International Trade Administration (2019) of the United States Department of Commerce and the World Steel Association (2022), the EU imports more steel than any other country or trading block in the world. The main countries of origin for that imported steel were the Russian Federation, Ukraine, Turkey and China. According to the International Monetary Fund (2019), the EU is the largest single market in the world accounting for over 20% of global economic activity. Therefore, if the EU sets a particular standard for products traded in its single market, this is likely to be of relevance to the global market.

1.2. Steel and the circular economy

There is potential for steel to become a circular product. There are two main pathways to producing steel. One is using the Basic Oxygen Furnace (BOF) and the other is the Electric Arc Furnace (EAF) (Wood et al., 2020; Vigna et al., 2021). Authors have noted that steel recyclable using an electric arc furnace (EAF) has the potential to reduce greenhouse gas emissions with respect to traditional steelmaking techniques

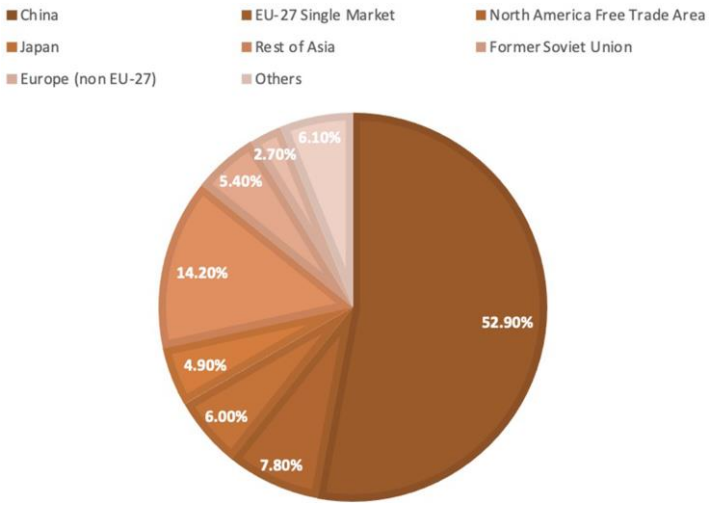


Fig. 1. Distribution of global steel production by country, region and trading block in 2021.
Source: World Steel Association (2022).

that use iron ore and metallurgical coal (World Steel, 2012; Broadbent, 2016; Evraz, 2016; Gupta, 2020). Literature connected to this issue, being embedded energy, will be explored in more detail in Section 1.4.

Hites (2020) found that, in 2017, the total amount of steel produced using EAF was around 29% of global production, though there had been a notable increase since 2012. Cooper et al. (2020) studied the potential for a country such as the United States, where around 70% of domestic steel is produced using EAF (Sandbag, 2022), to become self-sufficient in steel production using scrap steel. While the authors identified potential, they also highlighted there may be limits to circularity due to much of the current stock of steel being locked away in certain products (automobiles, planes, etc.), infrastructure and buildings for long periods.

Scrap steel is an internationally traded commodity (Gupta, 2020; London Metal Exchange, 2020). Söderholm and Ekvall (2019) summarised the findings of various studies undertaken over the last few decades that have sought to analyse the price elasticity of scrap supply, which suggested that scrap steel supply exhibited a relatively low sensitivity to price with a value of around 0.39. In other words, for every unit of increase in price, there would be a corresponding change in quantity supplied of 0.39 units. This supports an observation made by London Metal Exchange (2015), which operates some of the main markets in scrap steel, that it is a commodity with relatively low price elasticity.

Damuth (2011), however, illustrated that elasticity of supply may be as high as 0.89 depending on the kind of ferrous scrap being considered following a study using data from the United States. Damuth firstly noted that there are several types of scrap steel: (1) home scrap, (2) prompt scrap and (3) obsolete scrap. Home scrap is the waste material generated in steel production that is used in the same manufacturing plant where it is produced. Prompt scrap is waste material generated in steel production that is cleaned off the shop floor but sold to another party. Obsolete scrap is the steel contained in discarded products – such as automobiles, household appliances and demolition of built structures - that needs to be processed before it is suitable for use in an EAF. Given that the processing and transportation costs of obsolete scrap were much greater than for home and prompt scrap, it was this kind of ferrous scrap that exhibited the higher elasticity of supply when compared to that which was reported by Söderholm and Ekvall (2019).

The elasticity of supply of home, scrap and obsolete steel, as set out by Damuth (2011), is illustrated below. Fig. 2 considers the scenario in which supply is less elastic. This means that for every one unit increase in price, the corresponding increase in quantity supplied is less than one unit. The supply of home and prompt scrap arises because the waste stream needs to be managed immediately in the production environment, so it is not sensitive to price. Consequently, the supply curve for home and prompt scrap is vertical. Total supply is where home, prompt and obsolete scrap are combined. The lower elasticity scenario is likely to arise when home and prompt steel, whose supply is largely inelastic, make up a large part of the overall ferrous scrap supply curve.

Fig. 3, on the other hand, illustrates an increased level of elasticity. In this scenario, obsolete scrap makes up a greater proportion of overall supply when compared to home and prompt. Based on these relationships, the elasticity of supply of scrap is affected by the magnitude of demand.

Other authors have shown that, as ferrous scrap is an internationally traded commodity, it is mobile across regions and markets. The World Steel Association (2022), for example, published data that showed most of the countries and economic regions engaged in steel production import and export scrap steel. The majority of internationally trade steel comes from obsolete scrap, as the home or prompt scrap are generally used locally. The most prolific net exporters of scrap steel during the years 2020 and 2021 were the EU and the United States, while Asia was the largest net importer. It is worthy of note that neither Japan nor China engaged in importing or exporting of scrap steel during those two years (2020 and 2021). Notwithstanding, these figures suggest the elasticity of supply is affected by price signals across a range of markets and is not solely driven by domestic conditions.

It is also widely understood that recycling steel has the potential to reduce greenhouse gas emissions with respect to traditional steelmaking techniques that use iron ore and metallurgical coal. Çiftçi (2022) and Chen et al. (2022) illustrated the magnitude of the reduction in emissions depends upon the method of generating the electricity used by the EAF. For example, the use of low emission fuel sources such as renewables would produce a greater climate benefit than for electricity generated using fossil fuels such as coal or gas

The circular economy is greater in scope than just resource recovery.

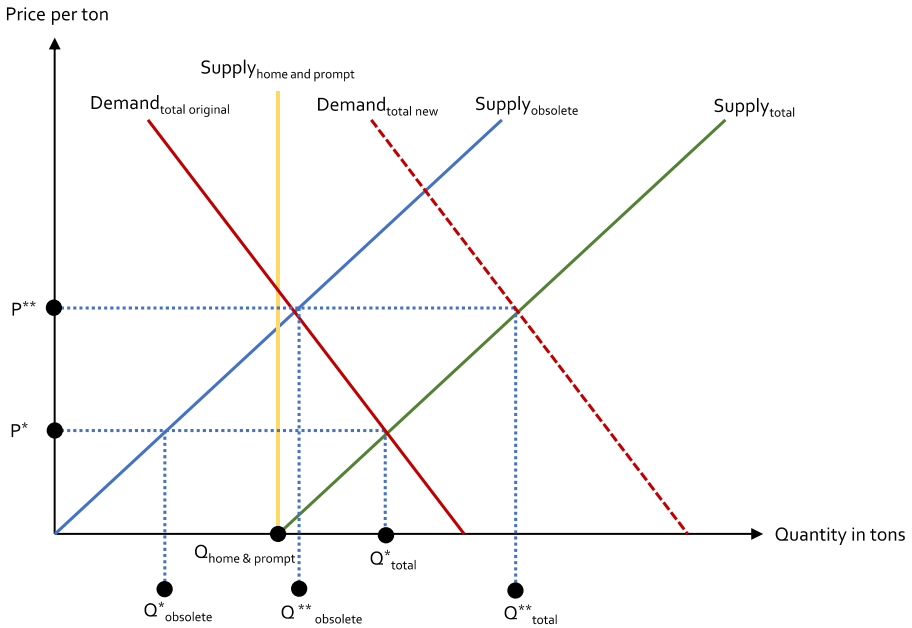


Fig. 2. Representation of supply, demand and price of scrap steel in a low elasticity environment.
Source: Adapted from Damuth (2011), page 6.

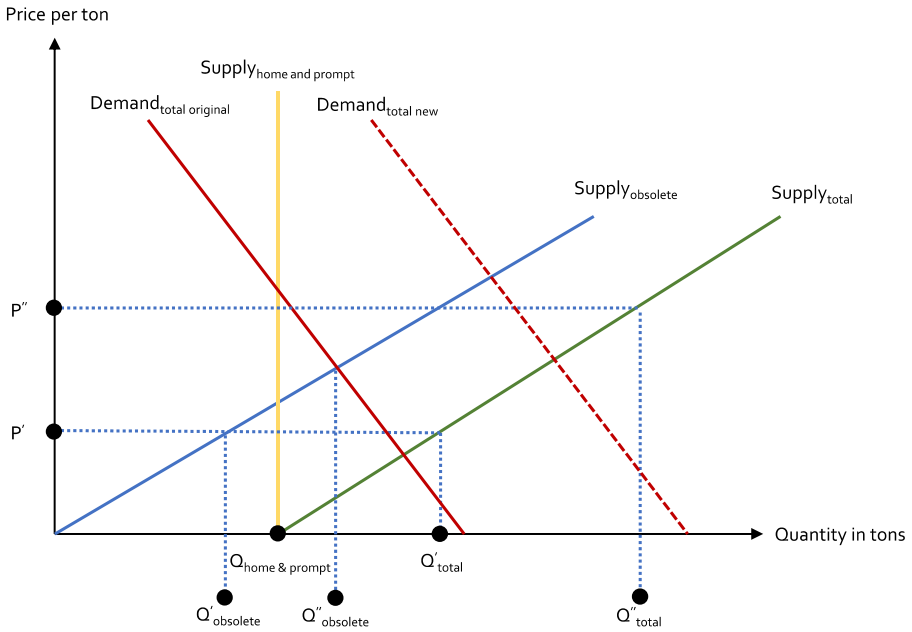


Fig. 3. Representation of supply, demand and price of scrap steel in a high elasticity environment.
Source: Adapted from Damuth (2011), page 6.

Scholars sometimes describe the circular economy as an extension of the waste hierarchy, where measures are arranged in order of priority according to perceived levels of desirability. These are: (1) Reduce, (2) Reuse, (3) Recycle, (4), Compost, (5) Energy recovery and finally (6) Landfill (Liang et al., 2021). Therefore, placed in context, recovery and recycling of scrap steel is situated in the approximate middle of this hierarchy.

1.3. EU emissions trading system

The EU ETS is a greenhouse gas cap-and-trade market, which is designed to reduce greenhouse gas emissions across the power generation and specific industry and transport sectors within the EU (European Union, 2003, 2015). The program was originally introduced in 2005 and is currently in its fourth trading phase. The first trading phase covered 2005-2007, the second from 2008-12 (encompassing the first commitment period of the Kyoto Protocol) and the third from 2013-2020 (encompassing the second commitment period of Kyoto). Under the EU ETS, a finite number of permits are issued each year by member states, which in aggregate make up the cap. The cap is reduced every year and covers emissions from installations that make up nearly 40% of total emissions across the EU (International Carbon Action Partnership, 2022). In principle, the cap is set lower than historical emissions levels so that there will be a scarcity in European allowances (EUA), which creates a price signal.

While authors such as Lovcha et al. (2022) have shown that scarcity is important for price discovery, others such as Rossetto (2019) have shown that surpluses can accumulate across the market though entities typically bank surplus EUAs on the expectation that they will become scarce again in future. This may arise, for example, as European governments commit to higher levels of greenhouse gas reductions. Bruninx and Ovaere (2022) found evidence in support of the finding. The authors noted that deeper emissions cuts proposed under the Green Deal have been among the main drivers of a steep increase in EUA prices during 2020 and 2021, which are illustrated in the historical price path of EUAs since inception is provided in Fig. 4 below (which shows spot EUAs only, which means units that are for immediate rather than future delivery).

Compliance each year is calculated based on the verified emissions data reported by each installation, who must then surrender one EUA for every ton of emissions. Failure to comply with this requirement results in a charge of EUR 100 per ton and an obligation for the given non-compliant installation to make good in the following year. According to the International Climate Action Partnership (2022), EU member states collected as much as EUR 31 billion from the sale of EUAs in 2021.

Some industries covered under the EU ETS qualify to receive free allocations of EUAs, which is designed to remove the cost obligation for those industries that either (a) compete with products imported into the EU that do not pay for greenhouse gas emissions in the jurisdiction of origin, or (b) compete in export markets where competitors' emissions are not constrained. Steel is one such industry. The level of free allocation is determined as the average emissions intensity of the top 10% most efficient plants across the EU for that product (International Climate Action Partnership, 2022).

1.4. Embedded emissions

Embedded emissions is an important concept in the context of CBAM because, together with the greenhouse gas emissions associated, it represents the liability that both importers and domestic manufacturers face in relation to their products (European Commission, 2021). Noted by The Chancery Lane Project (2022), embedded energy is a an interchangeable term with embodied energy, which is the amount of energy consumed in the manufacture and delivery to the customer of a given product. Embodied emissions, on the other hand, are the greenhouse gas emissions associated with that energy use. According to Pomponi et al. (2018), it has been studied by scholars over the years, though debates continue in areas of measurement, management and mitigation.

Measurement is a particularly complex matter, with scholars such as

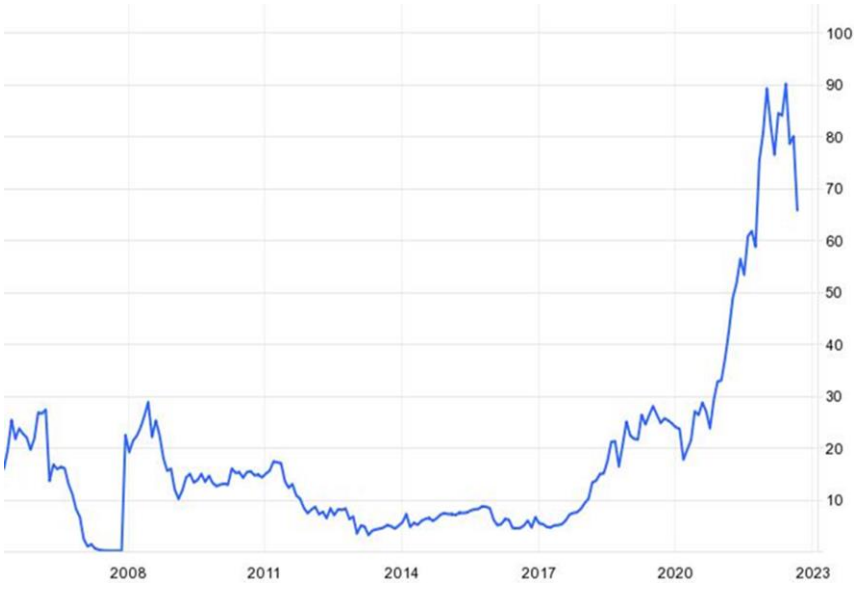


Fig. 4. Historical price path of spot European allowances (EUA) used for compliance with the EU ETS.
Source: Trading Economics (https://tradingeconomics.com/commodity/carbon).

Omar et al. (2014) illustrating the variations in embodied energy and emissions performance indicators of building materials between two countries – being Malaysia and Australia – that can arise through the use of default factors when compared to actual emissions. This is a finding supported by the work of Chen et al. (2022), who found differences even within regions of the same country: being China. Mehling and Ritz (2020) noted that the use of default factors would be a challenge in the context of a program like CBAM. They argued that it may lead to distorted results and would mute incentives for specific producers to seek out and implement technologies that assist in the reduction of emissions.

Liang et al. (2020) found that significant reductions in embodied emissions were possible from switching to EAF technology and using ferrous scrap steel as a feedstock. However, the results only tallied megawatt hours of electricity use and did not take into account the greenhouse gas intensity of the electricity generation. Chen et al. (2022) noted that this could result in embodied carbon reductions were slightly lower in magnitude than embodied energy, which may be the result of different carbon intensities of fuels used in the steel production process.

Skillington et al. (2022) studied a range of policies to encourage embodied emissions management across four countries. One of the conclusions was that many of the measures being used for embodied emissions management are being implemented on a voluntary basis by industry participants. Therefore, the means of implementation lacked financial incentives. While the authors did not refer to CBAM-style initiatives, this is a possible means of delivering a financial incentive that encourages reductions in embedded emissions.

2. Methodology

The aim of this study is to explore whether the European Union's proposed CBAM program, which is designed as a market-based measure for greenhouse gas abatement, is likely to drive demand for resource recovery and recycling. While CBAM, as it has been proposed by the European Commission, covers six different product areas, the focus of this study will be limited to steel products due to the complexity of covering all six. It seeks to answer the research question: *Will CBAM create an incentive for greenhouse gas reduction and resource recovery in steel production?*

2.1. Design

As the CBAM measure is not yet legislated and operational, the research question shall be answered on a forward-looking basis, utilising tools such as *logic* and *explorative* methods. The overall research design is graphically described below in Fig. 5 below. Following a literature review and the formulation of the research question, the empirical focus is placed on the specific implications for steel production. The study first applies *logic* to determine whether the introduction of CBAM, coupled with the removal of free allocation of EUAs to domestic producers, will lead to an incentive for greenhouse gas reduction. This is, in effect, an investigation of the applicability of the Porter Hypothesis to this case, which asserts that new environmental regulation can lead to corporate innovation and an eventual increase in competitiveness (Porter and Linde, 1995; He et al., 2020).

The next step is then to *explore* whether using scrap steel as a feedstock represents a genuine abatement measure available to both the entities being covered by CBAM and those domestic (EU-based) steelmakers that would no longer have access to future free allocations under the EU ETS once CBAM is introduced. The study does this by considering the performance of different steelmaking techniques, using a combination of default values and plant specific energy emissions factors, applied to historical spot emissions price (the market for EUAs that is for immediate rather than future delivery) observed in the EU ETS over a six month period. Finally, the study examines the relationship between EU carbon prices, scrap steel and finished steel over the same six month period to examine whether there is any evidence that free allocation is

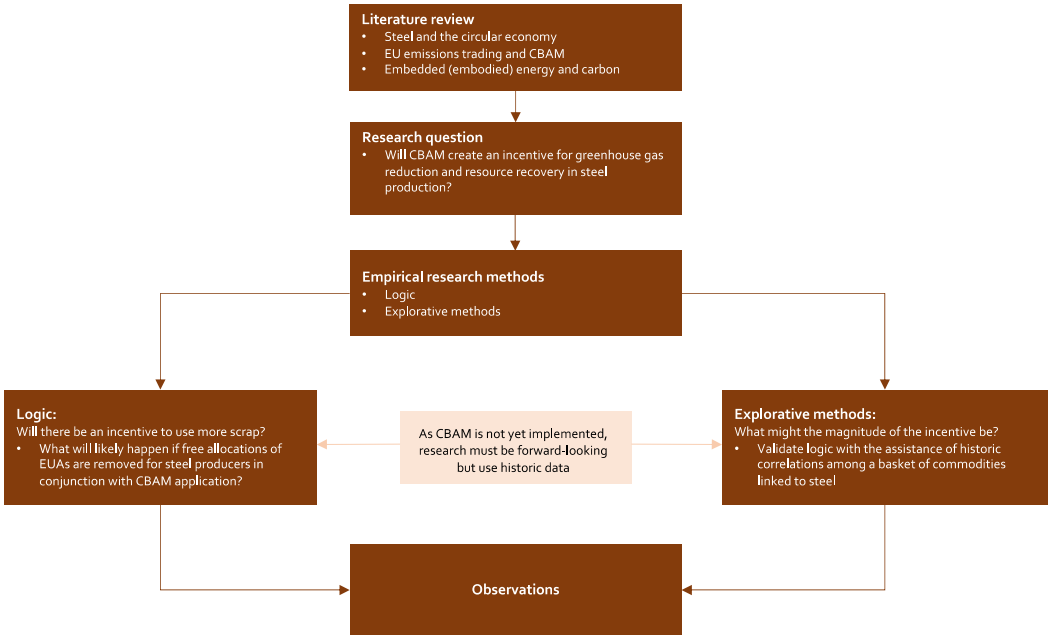


Fig. 5. Diagrammatic representation of the research strategy.

indeed muting the price signal to recycle as has been suggested by some (Sandbag, 2022). If this were validated, it would support the idea that CBAM will generate an incentive for abatement as removal of free allocation of EUAs remains part of the mechanism's design. Several authors have noted the limitations of using backward-looking studies as a basis for estimating future (Boal and Wiederhold, 2021; Awaworyi-Churchill et al., 2022). This is therefore an important limitation to note in the context of this study.

2.2. Data collection

There are four data sets of interest to completing the exploratory component of this research, which are embedded emissions intensity levels for various methods of steel production (*Data Set 1*), historical EUA carbon allowance prices (*Data Set 2*), historical scrap steel prices (*Data Set 3*) and historical finished steel prices (*Data Set 4*).

In respect of *Data Set 1*, ten separate estimates of the greenhouse gas intensity of steel based on emissions per unit of production have been collected from different sources, which include seven that are purely for the use of BOF technology and three that utilise EAF either on its own or for at least 50% of production. These are a combination of default factors and in situ measurements from installations in diverse locations around the world including the EU (Italy), China, Canada and Australia. These countries were selected to reflect a range of installations based in the EU and non-EU countries - from which imports into the single market may have been manufactured – to reflect the spectrum of technologies and the emissions intensities of current performance. The embedded emissions intensity figures are shown in Table 1 below, with the sources of the data shown in the first column. A column providing the classification of production technique is also provided, which includes BOF, EAF and various combinations of the two.

In respect of *Data Set 2*, historic EUA pricing data is available as far back as 2005 when the program first began. However, as illustrated in Fig. 4, there has been a significant increase in the price of these certificates in the last few years. One of the main drivers of the EUA prices, as noted in Section 1.3, was publication of the EU Green Deal. As this program is likely to remain, the more recent pricing environment can be considered the most probable scenario in the coming years. Accordingly, six months of data of the daily mean prices of spot EUAs was obtained from the European Energy Exchange (EEX), covering the trading days from July to December 2021 (inclusive).

In respect of *Data Set 3*, there are various international benchmark prices available for international trade in scrap steel. The most relevant based on volume are those in Turkey and India (Argus Media, 2022). Some commentators have suggested that a lot of scrap steel is being exported from Europe to these two countries, which is in part due to the stifling of price signals from the EU ETS caused by free allocation of EUAs given to steelmakers (Sandbag, 2022). Accordingly, six months of data of the daily prices of scrap steel for delivery a month ahead on both the Turkish and Indian indices was obtained from the London Metal Exchange (LME), covering the trading days from July to December 2021 (inclusive) to match the EUA data.

In respect of *Data Set 4*, there are various international benchmark prices available for trade in finished steel, though the most relevant is that of Northern Europe, given that is the market of interest for this research is the EU. Accordingly, six months of data of the daily prices of steel for delivery a month ahead on the Northern European index was obtained from the London Metal Exchange (LME), covering the trading days from July to December 2021 (inclusive) to match EUA and scrap steel data.

Average prices for the trading days from July to December 2021 (inclusive) for EU carbon (*Data Set 2*), scrap steel (*Data Set 3*) and steel (*Data Set 4*) are contained in the supplementary material in Annex 1.

Table 1
Embedded emissions intensity estimates used for steel production.

Source	Embodied carbon	Geographical reference	Remarks
Liang et al. (2020)	2.40 tCO_2e/t	China	70% BOF, 30% EAF
Chen et al. (2022)	2.38 tCO_2e/t	China	BOF only
Circular Ecology (2019)	2.36 tCO_2e/t	Global	Default factor
Evraz (2016)	2.08 tCO_2e/t	Canada	BOF only
Renzulli et al. (2016)	1.96 tCO_2e/t	Italy	BOF only
Hoffman et al. (2020)	1.85 tCO_2e/t	Global	Default factor
Pandit et al. (2020)	1.85 tCO_2e/t	Australia	BOF only
Liang et al. (2020)	1.44 tCO_2e/t	China	30% BOF, 70% EAF
Chen et al. (2022)	1.19 tCO_2e/t	China	50% BOF, 50% EAF
Evraz (2016)	0.44 tCO_2e/t	Canada	EAF only

3. Results

The first results to consider are those of applied *logic*, which is used to explore whether CBAM, coupled with removal of free allocation of EUAs to domestic producers, will lead to an incentive for greenhouse gas reduction. The first step is representation of the status quo on the assumption that there is only one means of steel production used, which is the blast furnace (BF) route. For goods produced inside the European Union, this is illustrated in Fig. 6 below. These are not real values but rather they have been chosen to illustrate the orders of magnitude. For example, the marginal production cost is shown as being eight units - which is assumed to include all relevant overheads, feedstock inputs, costs of transportation and amortisation of capital equipment needed for manufacture - whereas the market price is nine units. In simple terms, this would leave the producer with a potential gross profit margin of one unit. This is represented by the red arrow. It is also important to factor in the cost of meeting compliance obligations under the EU ETS. The cost to the EU-based producer of complying with the program is assumed to be achieved entirely by procurement of EUAs, which here is shown as two units. In order to protect that producer from the impacts of carbon leakage, the EU ETS provides free allocation of those EUAs, so that the transactions cancel one another out in the hypothetical producer's profit and loss. As a result, the producer has complied with its obligations under the EU ETS but has not suffered a competitive disadvantage in the global markets for steel. It should be underscored that this is a theoretical example and is not a representation of reality. It is merely used to represent the status quo. Actual free allocation levels are made according to best available technology benchmarks, so there will be some instances where the magnitude of free EUAs to emissions varies.

The next step is to illustrate status quo for the producer based outside the EU. In Fig. 7, its production cost is shown to be eight units, which is the same as the EU-based producer in Fig. 6. This is likely to be an incorrect assumption to make given all relevant overheads, feedstock inputs, costs of transportation and amortisation of capital equipment needed for manufacture that need to be included, though it is helpful to illustrate how this would lead to carbon leakage in the absence of free allocation of EUAs and prior to implementation of CBAM.

Fig. 8 considers the CBAM scenario in which an outcome equivalent to the policy intent, which is to equalise the competitive landscape between EU and non-EU based producers, is shown. The scenario includes a withdrawal of the free allocation system, which is done on the basis that importers of the products made outside the EU now pay for the cost of the CBAM certificates.

Allowing for the same margin as had been shown in Figs. 6 and 7, it is probable, under this scenario, that the price of the steel products offered in the EU to final consumers would increase to 11 units. This is because an additional cash cost of two units would be added to both kinds of producers' cost structure, which would need to be passed through to

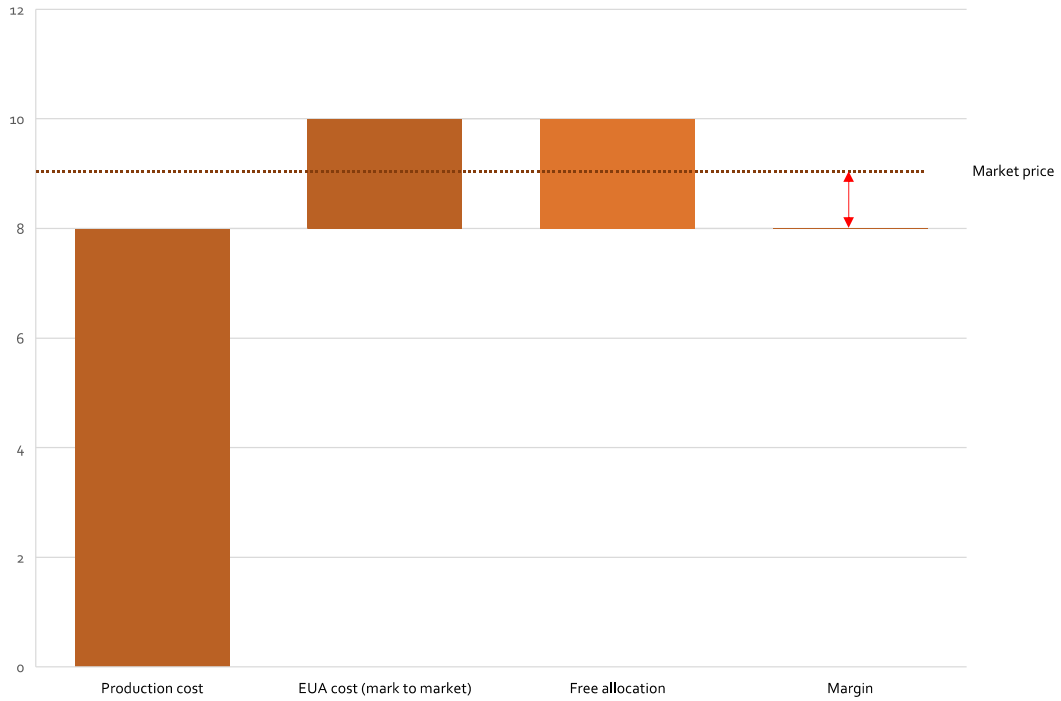


Fig. 6. Representation of the status quo on a per unit (t) basis for an EU-based producer.

Fig. 7. Representation of the status quo on a per unit (t) basis for a producer based outside the EU.

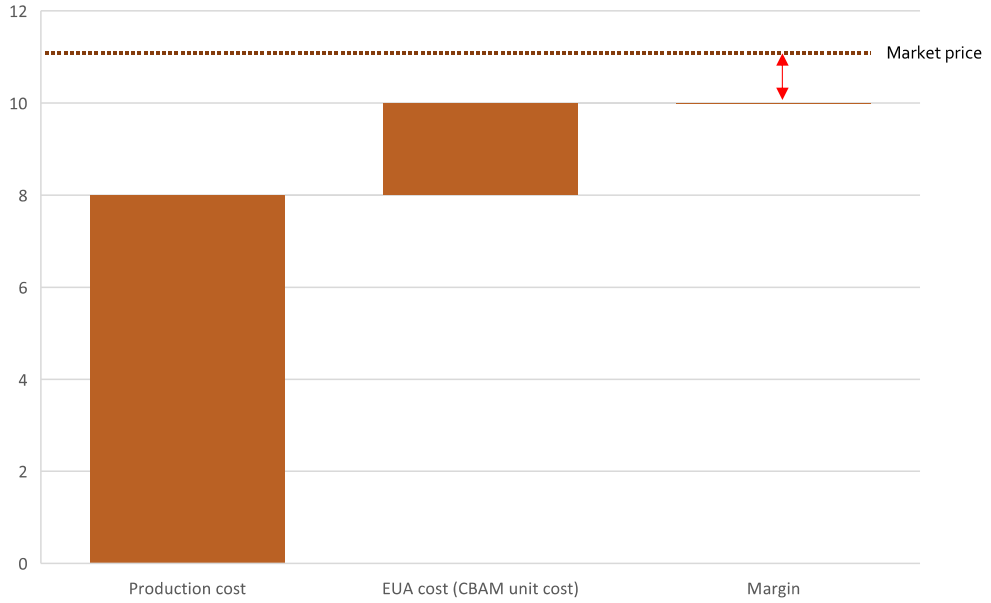


Fig. 8. Representation of production costs under CBAM on a per unit (t) basis for EU and non-EU producers.

customers if the production of steel were to remain a viable commercial activity. Therefore, it can be supposed via *logic* that there would be an incentive for any steel producer in this scenario to consider alternative means to manufacture products that has lower embedded emissions as this would reduce its carbon liability and by consequence its cost of complying with either the EU ETS (without free allocation) or CBAM. This provides support for the applicability of the Porter Hypothesis.

Extending then into the *exploratory* component, emissions intensity and carbon price data – taken as the average EUA price of the daily price levels over the six month time period, being EUR 62.42 - is combined and applied to determine a snapshot of costs of compliance. The results of the calculation are shown below in Fig. 9, with each dot representing

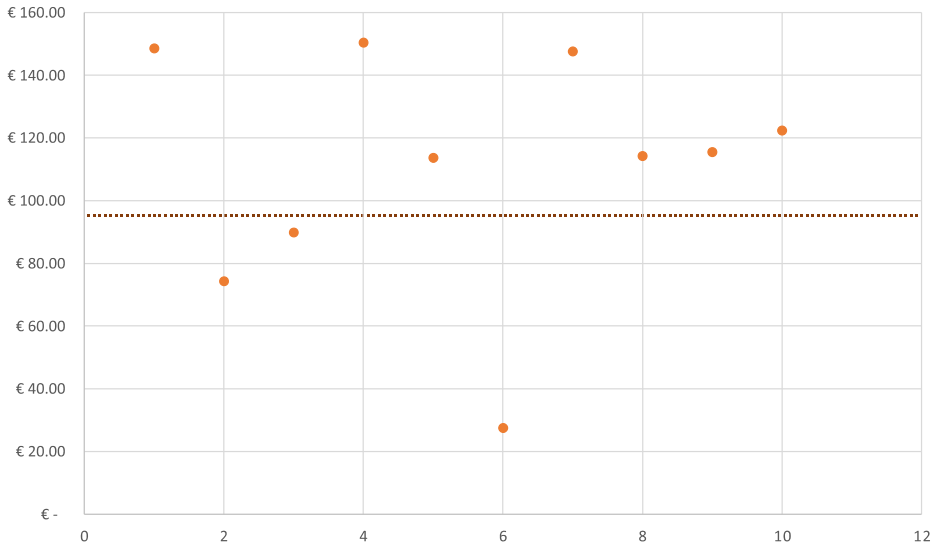


Fig. 9. Results of the overall EU ETS (without free allocation) and CBAM cost compliance validation and observation.

the 10 emissions intensities previously provided in Table 1, illustrating simple EU ETS (without free allocation) and CBAM compliance costs.

An average EU carbon price of EUR 62.42, while certainly not the peak, is quite high relative to the historical price trajectory since the EU ETS was introduced in 2005 (refer Fig. 4). While it is not within the scope of this paper to speculate on the future prices of EUAs, it is important to note that market prices of EUR 62.42 could be exceptional and may fall again within the time period for implementation of CBAM. Were prices to fall significantly in coming years, this would have a corresponding negative effect on the magnitude of the incentive.

It is worthy of note that all the results above the dotted line feature BOF as either the sole or predominant means of steel production. The results below the below the dotted line include the opposite, where EAF is either the sole or predominant means of production. Installations in the EU may not face the same compliance costs as those being imported as the domestic installations will have more flexibility in how they comply with the measure. This includes options to use previously banked EUAs.

Finally, the correlations of the different commodities is presented in Table 2 below. Over the time period investigated, there is little correlation between EU carbon prices and the prices of scrap steel based on the India and Turkey indices (25.63 and -6.73% respectively). This supports the observation by Sandbag (2022) that the current free allocation system is muting the incentive to recycle steel in Europe. This may change, notwithstanding, under the CBAM arrangements.

There is also a reasonably strong negative correlation between EU carbon and finished steel, shown here as -79.60%. In this context, the higher EU carbon prices rise, the more steel prices reduce. This could be an illustration that, the more expensive EU carbon becomes, the greater the incentive becomes to import steel from outside the EU (thereby reducing demand for European steel). This affords EU-based steelmakers the opportunity to profit by selling EUAs during periods of higher prices. Correlation does not necessarily imply a cause and effect relationship, though this does provide an economically rational and plausible explanation.

Scrap steel, if used by EAF-equipped steel producers with both compliance obligations and shortages of EUAs, has the potential to reduce the direct emissions of those producers. This supports the notion that CBAM could, over time, neutralise this option for EU-based firms by removing free allocation and increasing the incentive to abate. There will likely be a time lag for as long as the previously allocated EUA surpluses remain in the accounts of EU-based steelmakers (Rossetto, 2019). As demand increases, one may anticipate the correlation between EUAs and scrap will increase. Monitoring movement in these variables will become an important reference point for future research activity in this area.

Finally, it is important to note that the results are presented on the consideration of direct emissions only. If – as has been signalled by the European Commission (2022a) and noted in the introduction - indirect emissions are included at the conclusion of the CBAM transitional phase, this could negatively impact those producers who are connected to carbon-intensive electricity networks. For example, some of the advantages of utilising more scrap steel may be lost if the source of electricity used in the EAF were produced using an emissions-intensive fuel source such as brown coal. Notwithstanding, the challenges associated with reliably calculating and verifying indirect emissions information are so great that much work will be needed before the methodology for doing so can be defined.

Table 2
Correlations among steel, scrap steel and EUAs during July to December 2021 (inclusive).

Commodities	EUA	Scrap steel (India)	Scrap steel (Turkey)	Steel (N. Europe)
EUA	N/A	25.63%	-6.73%	-79.60%
Scrap steel (India)	25.63%	N/A	77.88%	-58.37%
Scrap steel (Turkey)	-6.73%	77.88%	N/A	-26.44%
Steel (N.Europe)	-79.60%	-58.37%	-26.44%	N/A

4. Discussion

The research outlined in this paper began with the question: *Will CBAM create an incentive for resource recovery and recycling in steel production?* While authors like Ma et al. (2014); Wood et al. (2020); Muslemani et al. (2021)and Vigna et al. (2021) have all considered decarbonisation pathways for steel that include resource recovery options, CBAM is a relatively new proposal and there are few scholarly studies on the specific impacts on the industry. This paper shows that utilising EAF, which by consequence means using scrap steel as a feedstock material, would yield a cost advantage for steel producers where EUA inputs are concerned. This is consistent with the ideas put forward by Çiftçi (2022) and Chen et al. (2022) that steel produced using recovered scrap steel is likely to yield a range of environmental co-benefits including greenhouse gas emissions. The research reveals evidence that free allocation of EUAs does mute the signal to use scrap steel within the EU and, with the removal of this feature under CBAM, the signal will strengthen.

It is, therefore, plausible to state that a program whose main objective includes the reduction of greenhouse gas emissions can amplify the incentive to recover waste materials. This is a significant finding, as it suggests policy makers seeking to support circular economy development may be able to link into programs orientated toward climate change goals. This is already in the European Green Deal - particularly within the parallel development of a Circular Economy Action Plan and Sustainable Products Policy alongside CBAM – though the direct synergies are less apparent. It would address the gaps identified by researchers like Skillington et al. (2022), who found a need for financial incentives to encourage efforts to deal with embodied emissions reduction across a range of building materials. Understanding how to increase support for circular economy business model development, building on the studies of authors such as Pieroni et al. (2019) and Nußholz et al. (2020), among others, will also increase. It can reduce regulatory burden in an environment where overregulation is identified by previous studies such as those by Shooshtarian et al. (2022) as a barrier to better waste management and resource recovery practice.

Another important point is that the rules for compliance with CBAM will be somewhat different to the rules for installations covered by the EU ETS. Under CBAM, for example, importers will not be allowed to bank certificates - that is, purchase them for use in the future at a time of choosing. The European Securities and Markets Authority (2022) and the European Commission (2022b) estimated that as many as 1.44 billion EUAs remained in circulation at the end of 2021. Under the EU ETS, as has been highlighted by Rossetto (2019), banking is permitted including where the allowances had been freely allocated. Consequently, EU-based installations will have more flexibility to comply with CBAM than importers. Importers would not have as many instruments available to manage the market risk associated with EU carbon prices as domestic producers, which could either delay or reduce the incentives to invest in EAF production facilities to utilise more obsolete ferrous scrap.

Damuth (2011) and Söderholm and Ekvall (2019) have also shown that other factors may affect both the supply and demand for ferrous scrap beyond overall market prices. These include broader economic conditions affecting construction activity, the availability of infrastructure to switch between EAF and BOF production, technical complexities of processing feedstock materials, especially associated with obsolete scrap and transportation logistics, particularly where scrap is internationally traded. Where EAF-produced steel competes with steel produced by other means like BOF, the costs of the underlying raw materials used in BOF like iron ore and metallurgical coal, are also important. Cooper et al. (2020) illustrated there is also a strong possibility that,

even if there is to be a strong price signal created by CBAM to make use of scrap steel, supply of obsolete scrap will be limited by the stock of used steel that is stored in existing buildings, vehicles, aeroplanes, among others, which may take many years and even decades to become available. The willingness of producers to capture CBAM-linked incentives will be affected by such feedstock supply factors.

The overall findings, along with the implications, set against the two issues previously identified in the introduction, are:

> *Issue 1. Carbon border measures represent a more effective way to reduce the effects of carbon leakage for incumbent producers than free allocation of emissions certificates, particularly due to the broadening of the incentive to abate such measures can deliver.*

This research reveals qualified support for this issue, as it it will become economically rational under CBAM to seek out the abatement opportunity afforded by utilisation of increased scrap, provided that it is coupled with a removal of free allocation of carbon permits. This would also support the applicability of the Porter Hypothesis, whereby environmental regulation will drive corporate innovation. The volume of obsolete steel available globally is the subject of uncertainty, connected to the stock problem where steel can remain in use for long periods before becoming salvagable. Increasing demand for scrap may therefore necessitate a deeper understanding of obsolete steel stocks.

> *Issue 2. Circular economic solutions such as resource recovery and recycling will lead to reductions in greenhouse gas emissions and vice versa, therefore an opportunity exists to use the same policy measures to advance both aims.*

CBAM, if implemented as it is currently designed and insofar as it relates to scrap steel, has the potential to support this aim. Recycling of steel is only a small component of the circular economy and deals in only a small range of the options available. Further work is needed to understand how climate action might deliver circular economic co-benefits and vice versa with other materials and at different stages in the hierarchy.

5. Conclusion

This study provides important insights into how CBAM might impact steel recycling on a forward looking basis. The final rules that will govern CBAM including the flexibility provisions that will be afforded to importers, as well as the future market conditions affecting the price of EUAs, will both be important determinants of the magnitude of the incentive. Final CBAM design issues will be particularly important to ensure that it adheres to the WTO principle of being non-discriminatory, which might otherwise provide the basis for political opposition to the proposal in the longer term. The EU ETS can become a flashpoint for international climate politics. For example, the EU ETS began covering inter-continental emissions in the aviation sector in 2012, though intense political opposition from non-EU countries eventually forced the EU to remove those flights from the market a few years later and defer action to the International Civil Aviation Organisation (ICAO).

Steel production is a capital-intensive business with long lead times for infrastructure investment. The capacity of the steel production market – in particular, the segment of the global industry that supplies steel demand in the EU - to make use of increased levels of ferrous scrap also depends upon the availability of EAF infrastructure to which production can be switched. Exactly how important perceptions of the long-term future are relative to the more near-term market price signals from a mechanism like CBAM is not, at present, well understood. There is uncertainty about the quantity of obsolete scrap that can be readily processed, which may inhibit investment. This is connected to the fact that steel remains in use for long periods of time (the stock problem). Recycled steel also faces competition: A significant amount of investment is going into green steel production that utilises hydrogen, which looms as another potential way to reduce emissions from steel production. There is also at least some basis to assert that CBAM may, in some cases, shift the location of where some ferrous scrap is used and not alter the global level of resource recovery.

Notwithstanding, there are implications arising from this study for policy makers who seek opportunities to promote circular economy. There is at least some potential for resource recovery to stem as a co-benefit of programs that target other environmental benefits like greenhouse gas reduction. A market-based approach like CBAM may influence the thinking of those seeking to address the viability gap associated with circular economic business models.

Role of the funding source

This paper was prepared during doctoral candidature with funding provided through The University of Adelaide, through a Faculty of Science, Engineering and Technology divisional scholarship. The funding provider played no role in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

CRediT authorship contribution statement

Daniel Rossetto: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.horiz.2023.100048.

References

Abnett, K. (2020). EU considers tax, emissions trading for carbon border plan. Reuters. Brussels, Reuters.
Argus Media. (2022). "Metal Movers: What is supporting the Turkish scrap price?" Podcast, from https://www.argusmedia.com/en/blog/2022/october/5/podcast-metal-movers-what-is-supporting-the-turkish-scrap-price.
Awaworyi-Churchill, S., Inekwe, J., Ivanovski, K., Smyth, R., 2022. Breaks, trends and correlations in commodity prices in the very long-run. Energy Econ. 108, 105933.
Bashmakov, I.A., 2022. CBAM and Russian export. Vopr. Ekon. (1), 90–109.
Bellora, C., Fontagné, L., 2022. EU in Search of a WTO-Compatible Carbon Border Adjustment Mechanism. Paris. Centre d'Etudes Prospectives et d'Informations Internationales (CEPII).
Boal, F., Wiederhold, J., 2021. Rethinking Commodities. J. Altern. Invest. 24 (1), 136–147.
Broadbent, C., 2016. Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy. Int. J. Life Cycle Assess. 21 (11), 1658–1665.
Bruninx, K., Ovaere, M., 2022. COVID-19, Green Deal and recovery plan permanently change emissions and prices in EU ETS Phase IV. Nat. Commun. 13 (1), 1165. -1165.
Chen, W., Yang, S., Zhang, X., Jordan, N.D., Huang, J., 2022. Embodied energy and carbon emissions of building materials in China. Build. Environ. 207, 108434.
Çiftçi, B. (2022). "Maximising scrap use helps reduce CO2 emissions." Raw materials Retrieved 13 September 2022, from https://worldsteel.org/steel-topics/raw-materials/.
Circular Ecology, 2019. Inventory of carbon and energy database. Circular Ecology. Bath.
Cooper, D.R., Ryan, N.A., Syndergaard, K., Zhu, Y., 2020. The potential for material circularity and independence in the U.S. steel sector. J. Ind. Ecol. 24 (4), 748–762.
Cosbey, A., Mehling, M., Marcu, A., 2020. Border carbon adjustments in the EU: Issues and options. Roundtable on Climate Change and Sustainable Transition, Brussels.
Damuth, R., 2011. Estimating the price elasticity of ferrous scrap supply. Nathan Associates Inc, Arlington.
European Commission (2019). The European green deal. european commission. Brussels. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions.
European Commission (2021). Proposal for a regulation of the European Parliament and of the Council establishing a carbon border adjustment mechanism. European Union, European Commission. COM(2021) 564 final.

European Commission, 2022a. European Green Deal: Agreement reached on the Carbon Border Adjustment Mechanism (CBAM). European Commission, Press Corner. Brussels.
European Commission, 2022b. Publication of the total number of allowances in circulation in 2021 for the purposes of the Market Stability Reserve under the EU Emissions Trading System established by Directive 2003/87/EC and of the number of unallocated allowances during the period 2013-2020. European Commission, Brussels.
European Securities and Markets Authority (2022). Emission allowances and associated derivatives. Brussels, European Securities and Markets Authority.
European Chamber of Commerce Taiwan, 2022. CBAM implications and solutions for industries in Asia. Eur. Chamb. Commer. Taiwan from. https://www.ecct.com.tw/cbam-implications-and-solutions-for-industries-in-asia/.
European Union, 2003. DIRECTIVE 2003/87/EC of the European Parliament and of the Council of 13 October 2003 Establishing a Scheme for Greenhouse Gas Emission Allowance Trading Within the Community and Amending Council Directive 96/61/EC. European Commission. European Commission, Brussels.
European Union, 2015. ETS Handbook. Brussels. European Commission.
Evraz, 2016. Evraz Canadian steel: Lower carbon footprint. Cleaner Steel, Toronto.
Gore, T. (2021). "The proposal for a Carbon Border Adjustment Mechanism fails the ambition and equity tests." The EU's Fit-for-55 package: The European Green Deal's fitness test Retrieved 14 September 2022, from https://eu.boell.org/en/2021/09/13/proposal-carbon-border-adjustment-mechanism-fails-ambition-and-equity-tests.
Gros, D., 2009. Global Welfare Implications of Carbon Border Taxes. Federal Reserve Bank of St Louis, St. Louis.
Gupta, S., 2020. Industry Address. LME Metals Seminar. London Metal Exchange, London.
He, W., Tan, L., Liu, Z.J., Zhang, H., 2020. Property rights protection, environmental regulation and corporate financial performance: Revisiting the porter hypothesis. J. Clean. Prod. 264, 121615.
Hites, B. (2020). "The growth of EAF steelmaking." Recycling Today Retrieved 26 September 2022, from https://www.recyclingtoday.com/article/the-growth-of-eaf-steelmaking/#:~:text=in%20the%20U.S.%2C%20are%20building,better%20part%20of%20a%20decade.
Hoffman, C., Van Hoey M. and Zeumer B. (2020). Decarbonisation in steel, McKinsey.
Horn, H., Sapir, A., 2013. Can Border Carbon Taxes fit into the Global Trade Regime? Federal Reserve Bank of St Louis, St. Louis.
International Carbon Action Partnership. (2022). "EU emissions trading system (EU ETS)." Fact Sheet Retrieved 26 September 2022, from https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-43.pdf.
International Monetary Fund, 2019. World economic outlook. Int. Monet. Fund. Update January 2019.
International Trade Administration, 2019. Steel Imports Report: European Union. Global Steel Trade Monitor. US Department of Commerce, Washington DC.
Liang, T., Wang, S., Lu, C., Jiang, N., Long, W., Zhang, M., Zhang, R., 2020. Environmental impact evaluation of an iron and steel plant in China: Normalized data and direct/indirect contribution. J. Clean. Prod. 264, 121697.
Liang, D., Liu, Z., Bian, Y., 2021. Match circular economy and urban sustainability: re-investigating circular economy under sustainable development goals (SDGs). Circ. Econ. Sustain. 1.
London Metal Exchange, 2020. LME Monthly Overview June 2020. London Metal Exchange.
Lovcha, Y., Perez-Laborda, A., Sikora, I., 2022. The determinants of CO2 prices in the EU emission trading system. Appl. Energy 305, 117903.
Ma, S.-H., Wen, Z.-G., Chen, J.-N., Wen, Z.-C., 2014. Mode of circular economy in China's iron and steel industry: a case study in Wu'an city. J. Clean. Prod. 64, 505–512.
Metal Exchange, 2015. Understanding Steel Scrap and the New LME Ferrous Contracts. London Metal Exchange, London.
Mehling, M., Ritz, R., 2020. Going beyond default intensities in an EU carbon border adjustment mechanism. Cambridge Working Paper in Economics 2087. University of Cambridge, Cambridge, United Kingdom.
Muslemani, H., Liang, X., Kaesehage, K., Ascui, F., Wilson, J., 2021. Opportunities and challenges for decarbonizing steel production by creating markets for 'green steel' products. J. Clean. Prod. 315, 128127.
Nußholz, J.L.K., Rasmussen, F.N., Whalen, K., Plepys, A., 2020. Material reuse in buildings: Implications of a circular business model for sustainable value creation. J. Clean. Prod. 245.
Pandit, J., Watson, M., Qader, A., 2020. Reduction of Greenhouse Gas Emission in Steel Production Final Report. CO2CRC Ltd, Melbourne.
Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2019. Business model innovation for circular economy and sustainability: A review of approaches. J. Clean. Prod. 215, 198–216.
Pomponi, F., De Wolf, C., Moncaster, A., 2018. Embodied Carbon in Buildings Measurement, Management, and Mitigation. Springer International Publishing, Cham.
Porter, M.E., Linde, C.v.d., 1995. Toward a new conception of the environment-competitiveness relationship. J. Econ. Perspect. 9 (4), 97–118.
Prasad, S., Sakura, F., Adcock, L., Newman, J., Kasner, S., Sullivan, N., Philippe, J., Bjorg Gylfadottir, H., King, D.K., Wilson, M., Sichlau, B., Willis, R., Ho, C., Dodd, K., Smith, C., Vahldiek, M., 2022. State of Circularity in Australia: Perspectives from the Field. Planet Ark, Sydney.
Qi, S., Xu, Z., Yang, Z., 2022. China's carbon allowance allocation strategy under the EU carbon border adjustment mechanism: An integrated non-parametric cost frontier approach. Sci. Total Environ. 831, 154908, 154908-.
Renzulli, P., Notarnicola, B., Tassielli, G., Arcese, G., Di Capua, R., 2016. Life cycle assessment of steel produced in an italian integrated steel mill. Sustainability 8 (8), 719 (Basel, Switzerland)-719.
Rossetto, D., 2019. Carbon markets beyond 2020: achieving breakthrough on paris agreement. Bloomb. Law J. Environ. Energy Rep.
Söderholm, P., Ekvall, T., 2019. Metal markets and recycling policies: impacts and challenges. Miner. Econ. Raw Mater. Rep. 33 (1-2), 257–272.
Sandbag (2022). "European scrap steel floats away under carbon market incentives." https://sandbag.be/index.php/2022/09/22/european-scrap-steel-floats-away-under-carbon-market-incentives/2022.
Shooshtarian, S., Caldera, S., Maqsood, T., Ryley, T., Khalfan, M., 2022. An investigation into challenges and opportunities in the Australian construction and demolition waste management system. Eng. Constr. Archit. Manag. 29 (10), 4313–4330.
Skillington, K., Crawford, R.H., Warren-Myers, G., Davidson, K., 2022. A review of existing policy for reducing embodied energy and greenhouse gas emissions of buildings. Energy Policy 168, 112920.
Starita, S., 2021. CBAM: An "Unfit for 55" Measure for Aluminium? EESC Public Hearing. European Aluminium, Brussels.
The Chancery Lane Project. (2022). "Embodied Carbon (Embedded Carbon)." Retrieved 27 September 2022, from https://chancerylaneproject.org/glossary/embodied-carbon-embedded-carbon/#:~:text=Embodied%20Carbon%20(also%20known%20as,and%20production%20of%20the%20Goods%5D.
Urazgaliev, V., Novikov, A., Menshikova, G., 2021. The global trend towards decarbonization of the economy, the introduction of the Carbon Border Adjustment Mechanism in the EU and the possible consequences for Russia. SHS Web Conf. 129, 9021.
Vigna, D., Stavrinou, Z., Gandolfi, A., Snowdon, N., Young, P., 2021. Carbonomics: Introducing the GS net zero Carbon Models and Sector Frameworks. Goldman Sachs Investment Research. Goldman Sachs Investment Research, London.
Wan Omar, W.-M.-S., Doh, J.-H., Panuwatwanich, K., 2014. Variations in embodied energy and carbon emission intensities of construction materials. Environ. Impact Assess. Rev. 49, 31–48.
White House (2021). FACT SHEET: The United States and European union to negotiate world's first carbon-based sectoral arrangement on steel and aluminum trade. Joint US-EU statement on trade in steel and aluminium,. Government of the United States of America.
World Steel, 2012. Sustainable steel at the core of a green economy. World Steel Assoc.
Wood, T., Dundas, G., Ha, J., 2020. Start with Steel. Grattan Institute, Melbourne, Australia.
World Steel, 2022. World Steel in Figures 2022.
Zhong, J., Pei, J., 2022. Beggar thy neighbor? On the competitiveness and welfare impacts of the EU's proposed carbon border adjustment mechanism. Energy Policy 162, 112802.

Daniel Rossetto is a world-leading specialist in green finance, climate risk management, clean energy development and finance, low-carbon transition strategy, carbon markets (design, implementation and commercial operation) and the circular economy with over 20 years of professional experience. He is currently undertaking his PhD at the University of Adelaide with his doctoral thesis entitled 'Incentives for the Future Trading of Construction and Demolition Waste'. Daniel regularly provides consulting input to major corporations and investment managers on developments in carbon markets and the economics of low-carbon technologies and has published several practitioner papers on green finance and climate-themed bonds through Bloomberg Environment.

Daniel has served as a company director in the United Kingdom for over a decade with Climate Mundial Limited. Prior to Climate Mundial, Daniel held the position of Executive Director at J.P. Morgan Chase. He joined J.P. Morgan as the firm commenced build out of its global environmental markets, carbon finance and carbon trading business, covering major compliance-driven emissions trading markets such as the European Union Emissions Trading System (EU ETS), the New Zealand ETS and California ETS. During his time at J.P. Morgan, Daniel was responsible for sales, origination and risk management and delivered some of the most important structured emissions transactions – linked to energy, agricultural & metals commodities - across the major market countries and regions.

Prior to joining J.P. Morgan, Daniel played an integral role in the developing the Enel Group's carbon strategy while employed at the firm's head offices in Rome. The strategy was designed primarily to ensure the firm's compliance with the EU ETS as well as the potential for international business units to generate compliance grade carbon credits. This incorporated emissions reporting, determining free allocations and sourcing of project-based credits via the Kyoto Protocol flexibility mechanisms - the Clean Development Mechanism (CDM) and joint implementation (JI). In his role, Daniel was responsible for global carbon market institutional affairs, covering regulatory and policy developments at the national, EU and United Nations institutions. During the period 2000-05, Daniel was a policy maker in Australia and was a member of the National Emissions Trading Taskforce (NETT) tasked with designing a national market-based program for reducing emissions across the electricity generation, industry and transportation sectors.

Daniel has worked extensively across the world including in Australia, Europe, Africa, Middle East, countries of the FSU, Latin America and Asia.

Chapter 6. Publication two and statement of authorship

This section presents the publication: *The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector*.

6.1 Statement of authorship

The statement of authorship is provided below in Table 9.

Table 9 – Statement of authorship for publication two

Title of paper:	The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector.			
Publication status:	Published	×	Accepted for publication	
	Submitted for publication		Unpublished and unsubmitted work written in manuscript style	
Publication details:	Rossetto, D. (2023). "The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector". Sustainable Horizons **6**: 100053. DOI: https://doi.org/10.1016/j.horiz.2023.100053 Reproduced in accordance with the publishing agreement.			
Name of principal author:	Daniel Marc Rossetto			
Contribution to the paper:	Research design, research execution and sole author			
Overall percentage:	100%			
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.			
Signature:				
Date:	14/03/2024			

6.2 Specific aims of the paper

Border carbon mechanisms were mentioned on a number of occasions by participants in the practitioner interviews (details of which are contained in Chapter 4). The aim of this paper was to explore answers to two research questions: (1) How significant is the problem of carbon leakage in the area of steel in the European Union and United States that would warrant action on border carbon mechanisms? (2): what are the specific areas in which such programs are vulnerable to challenge?

It addresses the research project's third objective, articulated in the introduction, which is to: *Examine the long-term feasibility of international measures – in particular border carbon measures – as a means of providing incentives for resource recovery and utilisation in construction and demolition waste practices*.

The paper tested the validity of both the US and EU cases with the *Porter Hypothesis*, which states that the existence of environmental regulation drives innovation within firms. In effect, theories of carbon leakage suggest the opposite of the Porter Hypothesis. That is, under carbon leakage, one would expect to observe migration of production to the region(s) with less stringent regulation rather than innovation.

The paper is significant in that it highlights the inherent vulnerabilities that border carbon mechanisms – including the EU's CBAM mechanism – face given specific legal and political context at the national and international level. This can affect the planning and implementation of innovation measures by steel firms, who might otherwise seek to invest in EAF technology and make greater use of scrap steel.

In drawing parallels between border carbon mechanisms and European experiences in attempting to cover inter-continental aviation within the EU ETS, there is evidence to suggest some firms will explore political avenues aligned to host country government positions before progressing immediately to innovation. This has implications for international trade in steel-making and the development of new agreements. Scholars who cited the paper in this chapter, namely Jakob and Mehling (2023), noted the both the strength of the concept of an international sectoral agreement as well as the complexity and long timeframe needed to prepare such a solution. This contains practice implications, as firms needing to make investment decisions face lengthy periods in which the relevant incentive and policy environment is insufficiently clear to allow absolute clarity in development, planning and execution. It also raises questions about how state-based emissions trading systems in the US would integrate into such a mechanism, given that the Federal government is responsible for trade negotiations and not all US states have carbon trading systems in place.

This adds considerable new insight into theories of corporate innovation including but not limited to Porter's hypothesis, which does not necessarily consider activities within the political economy as precedents for innovation in response to tighter environmental regulation.

6.3 Current citations

The paper has already been cited in:

Daud, R. et al. (2024). Bibliometric Analysis of Research Development on the Topic of State Border Development Using VosViewer. International Journal on Informatics Visualisation. **Vol. 8**, Number 1.

Mehling, M. (2023). "Supply-side crediting to manage climate policy spill-over effects." University of Cambridge Energy Policy Research Group Working Paper. Cambridge Working Paper in Economics.

Li, W., et al. (2023). "Analysis of China's steel response ways to EU CBAM policy based on embodied carbon intensity prediction." Energy. **Vol. 282**, 1 November 2023, 128812.

6.4 Publication two

The paper as published in June 2023 is now included.

Sustainable Horizons 6 (2023) 100053

Contents lists available at ScienceDirect

Sustainable Horizons

journal homepage: www.elsevier.com/locate/horiz

Original Research Articles

The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector

Daniel Rossetto *

School of Architecture and Civil Engineering, The University of Adelaide, Faculty of Sciences, Engineering and Technology

ARTICLE INFO

Keywords:
Border carbon adjustments (BCM)
Carbon leakage
CBAM
Common but differentiated responsibilities
EU emissions trading system
Inflation Reduction Act

ABSTRACT

Carbon leakage occurs when greenhouse-gas intensive production relocates to jurisdictions with less stringent or no emissions constraint. Observable increases in policy proposals to introduce border carbon mechanisms (BCM) to manage leakage risks have prompted scholars to examine potential conflicts with international trade rules. This paper examines longitudinal data over the period 2012-21 to reveal trends in the steel sectors of the US and EU and explores the consistency of proposed border carbon measures in those jurisdictions not just with international trade rules but also with environmental integrity, UNFCCC and sovereignty criteria.

The study identifies that the EU went from being an exporter to a net importer of steel over the period examined, while the US remained a relatively steady importer throughout the period. It also identifies areas within both the EU and US border carbon mechanism proposals that have the potential to prompt concerns from other countries in future; similar to the experiences in the EU with coverage of intercontinental aviation in its emissions trading system in 2012. It identifies that elements from global sectoral agreements would help to mitigate the risks of future challenges to border carbon mechanisms, which ultimately helped to overcome concerns within intercontinental aviation.

The article extends understanding of the role border adjustments can be applied within international climate and trade policy. As more countries seriously consider border carbon adjustments, the article will be of high value not just to policy makers but also managers of corporations seeking to navigate through decarbonisation challenges in hard to abate sectors such as steel, aluminium and cement.

1. Introduction and literature review

The concept of border carbon mechanisms (BCM) has been studied for decades, though only recently have governments attempted to develop them for implementation (Mehling et al., 2019; Eskander and Fankhauser, 2023). An area of relevance is whether such mechanisms are consistent with the principle of *common but differentiated responsibilities* (CBDR) contained in the United Nations Framework Convention on Climate Change (UNFCCC) (1992), which recognises that some countries with greater historical responsibility for greenhouse gas emissions shall be expected to move faster and more deeply on emissions curbs than others (Weijers et al., 2010; Singh, 2022). In effect, this means those countries with greater historical responsibility will need to constrain greenhouse gases more stringently and rapidly than others. Applying the principle in the context of global climate policy has led to concern among policy makers that the industrial competitiveness of developed countries would be impacted without necessarily reducing global emissions, giving rise to a concept known as carbon leakage (Lisowski, 2002; Howe and Sutter, 2017). Carbon leakage is said to occur when greenhouse-gas intensive production relocates to jurisdictions with less stringent or no emissions constraint. It can also arise when domestic production is replaced with imports from the less carbon constrained countries.

The main goal of border carbon mechanisms is to reduce the risk of carbon leakage. Despite nearly two decades of global experience with implementation of sub-national, national and regional carbon pricing systems, scholarly opinion about carbon leakage is not yet settled (World Bank, 2022). Grubb et al. (2022) and Eskander and Fankhauser (2023), for instance, found little evidence that carbon leakage was occurring, though these studies did find that other forms of shielding

* Corresponding author at: Room 3009, Horace Lamb, North Terrace 5005, South Australia.
E-mail address: daniel.rossetto@adelaide.edu.au.

https://doi.org/10.1016/j.horiz.2023.100053
Received 5 March 2023; Received in revised form 17 April 2023; Accepted 23 April 2023

such as free allocation of emission allowances, implemented as part of carbon pricing systems, has helped to mitigate the risks. Eskander and Fankhauser (2023) noted ambiguities in firm-level studies and called for further empirical work to be done to validate the possible leakage effects. Böning, Di Nino et al. (2023) concluded that there is evidence that corporations have been avoiding EU green regulations by outsourcing production to regions that are less stringent; and that the tendency is stronger in corporations with non-EU ownership.

Cosbey et al. (2019) identified that carbon border measures are susceptible to capture by interest groups given the complexity associated with their design and considering what is at stake. Other scholars noted that border carbon measures may face a difficult pathway to implementation. Horn and Sapir (2013) and Bellora and Fontagné (2022) observed that border carbon mechanisms can be perceived as protectionist industrial policy rather than bona fide climate action; and are at risk of being challenged under various multilateral forums - including the UNFCCC and agreements under the World Trade Organisation (WTO) rules (Sapir and Bruegel, 2020; Keen et al. 2022; Leonelli, 2022b; Maat, 2022).

The European Commission (2019) announced its plans for a Carbon Border Adjustment Mechanism (CBAM), which would become one of the most ambitious real case carbon border initiatives ever attempted. CBAM is designed to operate alongside the EU Emissions Trading System (EU ETS), eventually replacing *free allocation* of European Allowances (EUA) as the primary means of safeguarding against carbon leakage (Bellora and Fontagné, 2022; Böning et al., 2023). CBAM will introduce charges on imports into the EU single market based on the embedded greenhouse gas emissions of the products that are deemed at risk of carbon leakage – initially limited steel, aluminium, cement, hydrogen, fertilizers and electricity (Rossetto, 2023). It is also notable that, as the CBAM program has moved through the various stages of policy development, the appeal of similar mechanisms has grown elsewhere. The United States and the EU announced an intention to form a Global Steel and Aluminium Arrangement (GSAA) (White House, 2021), which would include, among other elements, a mechanism to address "*carbon intensity and global overcapacity*" (page 1). Recent policy consultation documents released by the Australian Government (2023) noted that many stakeholders now favour a CBAM-style border adjustment measure to mitigate carbon leakage risks by levelling the playing field for Emissions Intensive and Trade Exposed (EITE) industries.

While scholarly endeavour on border carbon measures has been focused primarily on the legal consistency of such measures with World Trade Organisation (WTO) rules (Keen et al., 2022, Leonelli, 2022b), few have sought to assess the geopolitical factors and historical precedents affecting whether the measures will become a sustainable feature of the policy landscape. It is in this context that the research described in this paper is presented. If European experiences in attempting to include intercontinental aviation within the EU ETS during the period 2008-2012 are taken into account, implementation of carbon border mechanisms that are being planned or considered may face resistance (Sapir and Bruegel, 2020). The first question that scholarly endeavour has, to date, been unable to conclude, is exactly how significant the problem of carbon leakage is in the specific case of steel. The second is, what are the specific areas in which programs are vulnerable to challenge, considering not just WTO rules but also other conventions?

The study begins with a literature review on border carbon mechanisms as well as their interaction with multilateral agreements and rules. It then explores experience gained from the European Union's efforts to cover intercontinental aviation in the EU ETS as well as developments in steel decarbonisation. Literature was searched on databases such as Google Scholar using keywords such as 'CBAM', 'carbon border taxes', 'border carbon mechanisms', carbon leakage, 'steel decarbonisation', 'embedded emissions', 'WTO', 'EU ETS', 'Inflation Reduction Act', 'aviation' and 'sovereignty'. Industry literature was identified using other, non-academic search engines using the same key words, as well as other financial markets and trade media sources.

1.1. Border carbon mechanisms and multilateral forums

Border carbon mechanisms are essentially unilateral policy instruments designed to limit carbon leakage. Unilateral refers to the fact they are designed and implemented by single countries or trading blocks, without seeking approval from any other countries. Being unilateral, BCMs have some potential to contradict provisions under multilateral agreements like the WTO and UNFCCC. Some scholars to analyse the impacts on enterprises in third countries and the risk that they might be challenged in the future (Overland and Sabyrbekov, 2022; Shen et al., 2023). Sapir and Bruegel (2020) studied the potential reactions to CBAM from countries that trade with the EU and noted that there are "dangers for international relations" (page 12-13) in adopting such an approach.

Numerous studies have been undertaken that analyse the nature of border carbon mechanisms; and whether they amount to a discriminatory action taken against products based on their country of provenance (Leonelli, 2022a; Maat 2022). Pirlot (2017) highlighted the need for environmental border taxes to draw an unambiguous link between them and the desired environmental outcomes. Cosbey et al. (2019) outlined a number of ways border carbon measures could be designed and the domestic policies they support. For example, if border carbon mechanisms were designed to support a domestic emissions trading system they would be regarded as a regulation under Article III.4 of the General Agreement on Tariffs and Trade (GATT). This means the regulation would need to be applied to the external producer in a way that was *no less favourable* than to the domestic producer and not violate a GATT principle of *Most Favoured Nation* (MFN), requiring that all products be treated equally regardless of the country of origin. A product should not, therefore, be discriminated against based purely on the emissions intensity of the country where it was produced. Keen et al. (2022) noted that subsidy programs are also relevant as they confer an unfair advantage to certain producers and, in doing so, contradict the WTO agreement on Subsidies and Countervailing Measures (SCM).

Another significant area of risk for border carbon mechanisms comes from climate policy itself. The UNFCCC introduced a specific *common but differentiated responsibilities* principle, which recognises that some countries are less responsible for climate change than others. It results in a natural differentiation of country according to development attainment and historical responsibility, which contradicts some of the ambitions of WTO rules that nations be afforded the same treatment (Keen et al. 2022). Leonelli (2022b) argues that this is addressable in the context of carbon border mechanisms through the way governments that collect income hypothecate the funds. For example, while all countries would be treated equally in terms of the trading across borders, the funds could then be invested into least developed countries. This approach is a concept but has not been tested.

1.2. Challenges in steel decarbonisation

Steel is an important material that is used in manufacturing, construction, transport and consumer applications throughout the world. In 2021, around 1.9 billion tonnes were produced globally and each tonne is believed to result in around 2 tCO2e of greenhouse gas emissions (including both direct emissions and indirect emissions, or scope one and scope two emissions and taking account of differences across countries), resulting in as much as 9% of global emissions. It is often labelled as one of the *hard to abate* sectors, where the technology needed to reduce its emissions to zero is either unproven or uneconomic (Cunningham et al., 2019; Wood et al., 2020; Muslemani et al., 2021; Horngren et al., 2023).

Steel is an internationally traded commodity and is a vital part of the economic prosperity of many countries. As public and consumer awareness of these issues increases, along with the broader societal focus

on environmental challenges such as climate change, many have suggested there is a need to revolutionise the way steel is produced (Gupta, 2020; Della Vigna et al., 2021). There are two generally accepted means of producing steel with lower emissions. The first of these is direct reduction green steel production and the second is green steel through recycling. Together with traditional, integrated steel manufacturing, each of these is summarised below, based reports by World Steel (2012), Wood et al. (2020) and Horngren et al. (2023):

1 *Integrated steel manufacturing* - in this process, iron ore is fed into a Blast Furnace (BF) along with coke, which is a form of metallurgical coal that is pre-treated in an oven to produce molten iron. The molten iron is then is then fed into a Basic Oxygen Furnace (BOF) along with a small amount of scrap steel, which is largely used to control the temperature of the process. The product of this process is crude steel, which is then further refined and cast before fabrication.
2 *Direct reduction steel manufacturing* - this is an adaptation of the traditional process, however it substitutes the need for metallurgical coal by producing direct-reduced iron rather than molten iron. A critical part of this process is the use of a reductant gas, which can either be natural gas or hydrogen. Direct reduced iron is then introduced to an Electric Arc Furnace (EAF), which is mixed again with scrap steel to moderate the reaction temperature. The product of this process is crude steel, which is then further refined and cast before fabrication.
3 *Steel recycling* - the resource and energy inputs of steel production can be substantially reduced is through the increased recycling of steel and its use in EAF technology. This approach can be used in conjunction with either traditional or direct reduction steel making, with Rossetto (2023) illustrating the potential reductions in emissions per tonne of steel achievable through increasing the percentage use of EAF.

Della Vigna et al. (2021), Horngren et al. (2023) and Bloomberg New Energy Finance (2023) all noted that decarbonisation is technically possible by integrating renewable energy into hydrogen production and using carbon capture technologies, though the costs and risks are largely commercially prohibitive.

1.3. The approach of the European Union

The European Environment Agency (2021) reported that, in 2019, the EU emitted some 4,067 million metric tonnes of carbon dioxide equivalent (tCO_2e) greenhouse gases. This represents a 29% reduction from its 1990 baseline, *en route* to an interim target of a 55% reduction by 2030 and eventual net zero emissions by 2050. One of the primary mechanisms for reducing the EU's emissions, the EU ETS, caps scope one (direct) emissions in the power generation sector, stationary energy emissions from industry and the domestic aviation sector across the entire European Union. The cap also applies to some participating countries that are not EU member states, such as Iceland, Norway and Liechtenstein (International Carbon Action Partnership, 2022). The EU ETS was first introduced in 2005 and is now in its fourth trading phased of 2021-2030. Entities covered by the EU ETS are required by law to report verified scope one emissions annually and then surrender an equivalent number of carbon allowances to the relevant member state. In 2021, verified emissions in the EU ETS had been reduced to 1,307 million tCO_2e from 2,065 million tCO_2e when the program first began in 2005 (European Environment Agency 2021).

As mentioned in Section 1, the European Commission is advancing design of its CBAM initiative. Maat (2022) notes that the CBAM is a unilateral policy initiative, therefore third countries are not afforded any role in the system's design. CBAM is being designed to replace *free allocation* within the EU ETS. Under the free allocation system, European member states have been granting a large portion of the carbon allowances needed to comply with the EU ETS to installations deemed to be at risk of carbon leakage (European Commission, 2021a). This includes a number of industrial sectors, which is similar to the coverage model of the CBAM which includes industries producing steel, cement, aluminium, hydrogen, electricity generation and fertiliser products. For the remainder of EU ETS participants, free allocation is being removed in favour of public sale of European Allowances (EUA) primarily via auction. EUA sales are becoming a significant revenue earner for member states, with International Carbon Action Partnership (2022) noting that over EUR 31 billion was earned in 2021. Several recent studies have shown that free allocation mutes the incentive for the industries receiving them, particularly steel, to reduce emissions (Grubb et al., 2022; Sandbag, 2022; Rossetto, 2023).

In an environment where the longer term aspirational goal is for net zero emissions by 2050, free allocation may be unnecessarily delaying decarbonisation investment within the so-called hard-to-abate sectors (Geels and Gregory, 2023). The necessity to accelerate decarbonisation toward the EU's net zero goal by 2050 is cited as a reason to move forward with CBAM (European Commission, 2021b). Notwithstanding the validity of this goal, Sapir and Bruegel (2020) reported on the potential political reaction to CBAM from third countries, likening it to previous efforts by the EU to cover intercontinental aviation in the EU ETS (Covered in Section 1.5).

1.4. The approach of the United States

The US Environment Protection Agency (2023) reported the US emissions in 2021 were 5,593.5 million tCO2e, which is approximately half way to the national target of being 50-52% below 2005 levels by 2030 en route to net zero by 2050. Unlike the European Union, the United States does not have a national emissions trading system similar to the EU ETS despite many notable attempts over the years that have failed to gain enough political support (Howe and Sutter, 2017). A number of US states have proceeded with their own cap and trade programs like California and in the north-eastern Regional Greenhouse Gas Initiative (RGGI), though there is no uniform, legally binding national carbon price in the US (World Bank, 2022). At the federal level, instead, the US has now taken a different approach to cap and trade carbon pricing. In 2022 it legislated the Inflation Reduction Act (2022) (the Act), which defines incentives for the deployment of clean energy and advanced low-emission manufacturing techniques. These incentives come in the form of tax credits and grants for implementation of clean energy and advanced industrial technology (Hogan Lovells, 2023). The definition of advanced industrial technology provided under the Act is broad and encompasses those "…designed to accelerate greenhouse gas emissions reduction progress to net-zero at an eligible facility" (Part 6. g). This is deemed to cover implementation of low-emissions technologies at manufacturing plants, including but not limited to steel production.

As mentioned in Section 1, the US and the EU announced an intention to form a Global Steel and Aluminium Arrangement (GSAA) (White House, 2021), which would include, among other elements, a mechanism to address "*carbon intensity and global overcapacity*" (page 1). While there is little detail on how the GSAA would operate currently available in the public domain, scholars understand it to be bilateral cooperation on a border carbon measure similar to CBAM and have used a term carbon clubs approach to describe this kind of cooperation (Leonelli, 2022a). While this might appear to represent a significant difference between the EU and US, Tucker and Meyer (2021) and later Meyer and Tucker (2022) argue that the US approach embodied in the Inflation Reduction Act, along with state-based programs forms, an equally valid domestic policy basis as an ETS alongside which to implement a border carbon mechanism.

1.5. Intercontinental aviation in the EU emissions trading system

Sapir and Bruegel (2020), when looking at the potential political

reaction to CBAM, drew comparisons between previous efforts to cover emissions from intercontinental aviation in the EU ETS to border carbon mechanisms. Under this measure, the EU had passed legislation in 2008 that would make airline operators liable for emissions from flights arriving at its airfields from airports located in other continents from 1 January 2012 (European Commission, 2008). For example, a flight leaving Singapore for Frankfurt would be liable for the emissions of that entire flight, notwithstanding it only travelled for the last few thousand kilometres in EU airspace. Under the coverage model introduced, airlines received a generous amount of free allocations and could use offset credits to cover some or all of their liability. While this may have appeared at the beginning to be a fairly sensible way to incentivise emission reductions from intercontinental aviation, it attracted criticisms from 23 nations – including India, Brazil Chile, China, Nigeria, South Africa, Saudi Arabia, Singapore and the United States, among others - that believed the EU was impacting the sovereignty of other nations to create a liability for emissions arising outside its territory. Working together, these 23 nations warned the EU of retaliatory measures which even included threats to legislate that airlines domiciled in their countries be prohibited from complying with the EU ETS, while calling for design of a multilateral approach to reducing emissions from intercontinental aviation through the International Civil Aviation Organisation (ICAO), which is itself a branch of the United Nations (Russian Aviation, 2012).

As reported by Sheahan and Bryan (2012), it was not until ministers in the EU countries where Airbus planes are manufactured were threatened with boycotts that enough pressure was applied to enable a suspension of the provisions for coverage of intercontinental aviation in the EU ETS to allow time for ICAO to design the mechanism called for by the group of 23 nations. Eventually, ICAO finalised a mechanism that has become known as the Carbon Offsetting and Reduction System for International Aviation (CORSIA) and the EU ETS provisions were removed (World Bank, 2022). Sapir and Bruegel (2020) noted that, while the 23 nations proposed reviewing the EU ETS provisions for their consistency with WTO rules, the primary driver of their opposition was that of sovereignty. While the study of sovereignty is a deep field, in this context it refers to right of a nation state to determine the laws and regulations on its own territory - also known as self-determination - and not have them decided upon or imposed by another entity (Goodman and Jinks, 2003; Kurtulus, 2005; Edelstein, 2022).

2. Methodology

The methodology of this study is designed to explore answers to two research questions about border carbon mechanisms, which were first identified in the introduction (Section 1). Accepting that designing and implementing border carbon mechanisms is going to costly, time consuming and controversial, the first question is: How significant is the problem of carbon leakage in the area of steel in the European Union and United States that would warrant action on border carbon mechanisms? The second is: what are the specific areas in which such programs are vulnerable to challenge? The paper is also deductive, testing the validity of the US and EU cases with the *Porter Hypothesis*, which states that the existence of environmental regulation drives innovation within firms (Porter and Linde, 1995; Shao et al., 2020). In effect, theories of carbon leakage suggest the opposite of the Porter Hypothesis. That is, under carbon leakage, one would expect to observe migration of production to the region(s) with less stringent regulation rather than innovation.

2.1. Design

In order to answer the first question, exploratory quantitative longitudinal analysis is deployed to evaluate key trends and patterns in greenhouse gas emissions and steel production data in both the EU and US covering a decade (calendar years from 2012-21 inclusive). The longitudinal analysis explores two specific indicators. The first concerns changes in the greenhouse gas intensity of steel production per tonne over the time period. The second concerns the degree of change in import reliance over the period, measured as the net imports (imports minus imports of tonnes of finished steel) as a percentage of *apparent consumption* of steel. Apparent consumption is the total production of steel in a given region net of the imports, exports and changes in stock, taking into account raw material use and finished steel (Eurofer, 2020). In considering these trends, the research tracks sector-wide advancements made in both the EU and US toward decarbonisation of steel to verify the magnitude of efforts being made. It also considers the extent to which the US and EU are becoming more (or less) reliant on imports in order to meet demand for steel in the respective economies. This paper, therefore, addresses the need for further empirical work to validate possible leakage effects identified by Eskander and Fankhauser (2023). It will also provide a basis for considering the applicability of the Porter Hypothesis.

In order to answer the second question, qualitative analysis provides a basis for assessing the border carbon mechanism approaches – combined with the domestic approaches where appropriate - being used by both the US and EU against the critical criteria identified in the literature review that would otherwise make them vulnerable to challenge. These criteria, which are based on environmental integrity, WTO consistency, UNFCCC consistency and sovereignty impact criteria, are as follows:

Criterion 1 *Environmental integrity*: Encompassing consideration of whether the approach is likely to reduce emissions. For example, does it have the potential to reverse an existing trend or remove a known impediment to abatement in the steel sector?

Criterion 2 *WTO consistency*: Including whether there is evidence that the measure is likely to levels the playing field, meaning that emissions constraints or production incentives linked to abatement will be demonstrably similar in all relevant countries;

Criterion 3 *UNFCCC consistency*: Covering whether there is evidence the measure addresses or is consistent with common but differentiated responsibility;

Criterion 4 *Sovereignty*: Taking into account whether the measure avoids impacting one or more trading partners' sovereignty, being the right of a nation state to determine the laws and regulations on its territory and not have them decided upon by another entity.

A scoring system deployed allocates a maximum of one point is allocated for each criterion. A score closer to four would therefore mean the measure is more sustainable in the longer term, whereas a score closer to zero would indicate a higher level of risk. This component of the study will also inform deductive investigation of the validity of Porter's Hypothesis, as innovation in corporate response is connected not only to the presence of environmental regulation but also its perceived sustainability.

2.2. Data collection

In order to carry out the longitudinal analysis, three data sets are required covering both the EU and the US. These are described below:

Data set 1 *Steel production*: including the splits between traditional or integrated steelmaking (method 1 in Section 1.2) and methods that use EAF technology (methods 2 and 3 in Section 1.2). Sources of data are the US government (US Geological Survey), The European Steel Association and the World Steel Association;

Data set 2 *Steel imports, exports and apparent consumption*: across both the US and EU. The sources of this data are the US

government (US Geological Survey), The European Steel Association and the World Steel Association;

Data set 3 *Scope one greenhouse gas emissions*: from steel production across both the US and EU. Sources of data are the US Government (Environment Protection Agency) and the European Environment Agency and the EU Transaction Log (EUTG), which supports implementation of the EU ETS.

All data used in the study is located in the supplemental information contained in Annex I.

3. Results

Results of the research are presented below in Sections 3.1 (quantitative longitudinal study) and Section 3.2 (qualitative analysis).

3.1. Quantitative longitudinal analysis

Changes in the scope one (direct) greenhouse gas emissions intensity of steel production in the US and EU over the period 2012-2021 are provided in Fig. 1. Intensity in the EU has remained relatively stable over the timeframe with a slight increase from 0.722 tCO_2e per tonne of steel in 2012 to 0.738 tCO_2e per tonne of steel in 2021. This is confirmed by the positive gradient trend line, which is also shown in the figure. While there has been some volatility, the intensity recorded in 2012 is the minimum while the maximum values were reached in 2015 and 2016 with 0.764 tCO_2e per tonne of steel. On the other hand, the US has shown a steady reduction from 0.607 tCO_2e per tonne of steel in 2012 to 0.467 tCO_2e per tonne of steel in 2021. This is confirmed by the negative gradient trend line. The intensity recorded in 2019 of 0.457 is the minimum whereas a maximum of 0.617 tCO_2e per tonne of steel was observed in 2014.

Overall emission intensity of steel production in the US is consistently lower than in the EU, which is plausible given that EAF makes up more than half of US steel production and is increasing. The US is also illustrating consistent improvements in intensity, whereas the EU is stagnant. This is noteworthy given that the EU ETS has been in place throughout the period.

Fig. 2 provides the level of import reliance in the US and the EU in relation to steel. Changes in net steel imports were much more pronounced in the EU than in the US. The EU began the period as a net exporter of steel as seen by -11.79% net imports in 2012. A steady increase in imports relative to exports led the EU to end the period as a 7.3% net importer. The positive gradient trend line confirms this phenomenon has been relatively consistent over the 10 year timeframe. The US on the other hand has remained a net importer over the entire period at levels always greater than 12% except for 2020, which also coincided with the year in which the Covid-19 pandemic response began. The trend line suggests that the important reliance level is falling, albeit the very low gradient suggests that the US is not experiencing great change in this area.

The magnitude of change in the EU, from net exporter to importer, indicates that there are some changes underway within the sector. Apparent steel consumption rose from 132 million to 149 million metric tonnes in the EU over that timeframe. While much of the difference is being made up through imports, there is insufficient evidence to conclude that this equates to carbon leakage.

3.2. Qualitative analysis

Results of the qualitative analysis are provided in Table 1 below. Both the US and EU approaches score two out of four against the four criteria, indicating some vulnerabilities exist. In both cases, the environmental integrity criterion is met. The EU program appears most likely to be designed in a manner that is consistent with WTO rules, though some concerns exist over the impact it may have on sovereignty in third countries. Neither of the approaches, despite being primarily focused on reducing emissions and tackling climate change, appears to address common but differentiated responsibilities; and therefore do not score in the area of consistency with UNFCCC criteria. Moreover, there is an inherent contradiction between the level playing field approach that is needed for WTO consistency and common but differentiated responsibilities as applied steel producers based in different countries.

4. Discussion

This study sought to answer two research questions. The first question was: How significant is the problem of carbon leakage in the area of

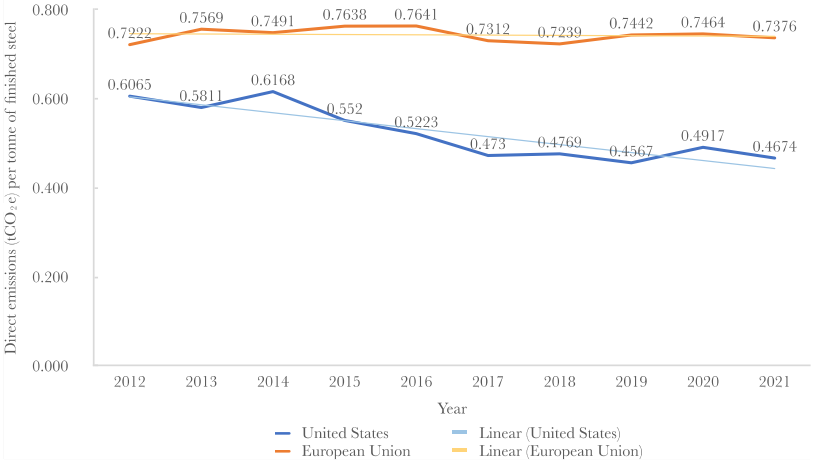


Fig. 1. Emissions intensity of steel production in the US and EU during the period 2012-2021.
Sources: US Environment Protection Agency, European Environment Agency, USGS, European Steel Association & EUTL.

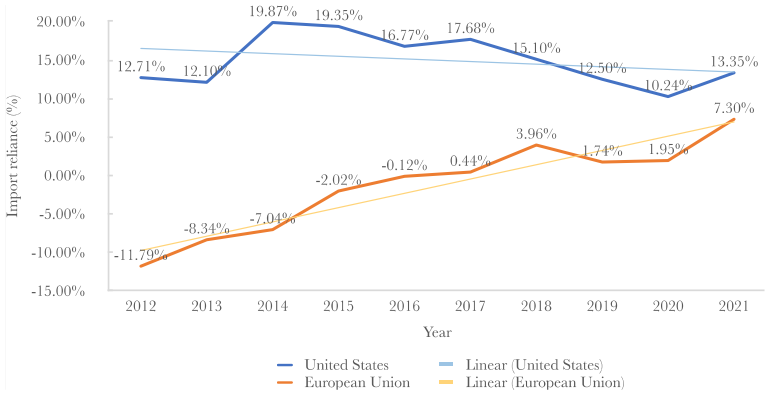


Fig. 2. Steel import reliance changes over the period 2012-2021 in the US and EU.
Sources: US Environment Protection Agency, European Environment Agency, USGS, European Steel Association & EUTL.

Table 1
Qualitative scoring matrix for the European Union and the United States. Three references are cited in table 1. We have placed in table caption please check. (Rossetto, 2023; Cooper et al., 2020; Poljak and Tran, 2023).

Criterion	Criterion description	Performance against criterion		Performance against criterion	
		European Union	Score	United States	Score
1 Environmental integrity	Encompasses consideration of whether the approach is likely to reduce emissions. For example, does it have the potential to reverse an existing trend or remove a known impediment to abatement in the steel sector?	The European Commission has not yet clarified how free allocations to existing industries at risk of carbon leakage will be scaled back or removed with CBAM, so it is difficult to predict the magnitude of emission reductions. However, as shown in studies (Rossetto 2023) the removal of free allocation itself would create a signal for abatement for producers based inside the EU. Competitive pressures would likely create a price signal also for those based outside the EU and there is evidence, as shown in Section 5.1 (Figure 2) that imports of steel are making up increasing amounts of the difference between apparent consumption and domestic production. Therefore, this criterion can be satisfied with a reasonable probability.	1	While there are few details about how the GSAA would be applied at this stage, the Inflation Reduction Act is a voluntary-style, opt-in program available to those steel producers who see an advantage in participating. It is not like a cap and trade program. There are no legally binding requirements that act as safeguards against growth of emissions though a growing number of states currently do have local cap and trade programs. The US already has a relatively high share of EAF steelmaking and studies have shown there will be limits getting to greater amounts due to constraints on scrap steel availability (Cooper, Ryan et al. 2020). The US's already low emission steelmaking profile would make it difficult for non-US produced steel to compete on an emissions basis. For these reasons, emission reductions are likely.	1
2 WTO consistency	Encompasses whether there is evidence that the measure is likely to levels the playing field, meaning that emissions constraints or production incentives linked to abatement will be demonstrably similar in all relevant countries.	The European Commission has made it clear it intends to design CBAM in a way that is consistent with WTO rules. Provided that free allocation is removed for EU-based producers and indirect emissions are eventually included in the calculus for imported products (given that the EU-based producers must also purchase carbon inclusive electricity), then a level playing field is possible. Therefore, there is a reasonable chance of meeting this criterion.	1	The US domestic approach provides a range of subsidies from local content incentives to grants, concessional loans and tax credits, for low emission steel production. These subsidies are only available to firms and projects meeting specific US-based criteria. The US makes the case that the GSAA will be to tackle subsidies offered to steel producers in non-US locations, so it would likely argue that it levels a playing field that is already punitive to US-based producers. US imports of steel have not been growing rapidly as seen in Section 5.1 (Figure 2), which dilutes the argument that new imports are flooding the US steel market. On balance, it is difficult to conclude that a level playing field is likely, especially in a context where the subsidies available under the Inflation Reduction Act are reported to be leading to substantial advantages for US-based producers (Poljak and Tran 2023). Therefore, not enough evidence exists to score against this criterion.	0
3 UNFCCC consistency	Encompasses whether there is evidence the measure addresses or is consistent with common but differentiated responsibility.	There is no information yet available on what the European Commission or member states would do with the funds collected under CBAM. By treating every importer of steel similarly to be consistent with WTO rules, it is unlikely that it will be able to show that CBDR principles will be met. Therefore, not enough evidence exists to score against this criterion.	0	There is no information yet available on what the US would do with any funds collected as a result of implementing the GSAA. In the absence of any further information, it is unlikely that one can conclude that CBDR principles will be met. Therefore, not enough evidence exists to score against this criterion.	0
4 Sovereignty	Encompasses whether the measure avoids impacting one or more trading partners' sovereignty, being the right of a nation state to determine the laws and regulations on its own territory and not have them decided upon or imposed by another entity.	Despite any potential merits of CBAM, it is fairly likely that it will result in the EU collecting charges that relate to business activities in third countries. It is true that importers will be able to net off the eventual CBAM charges with equivalent emissions costs incurred in the country of a steel product's origin, the current drafting of CBAM would still require that the charge would need to be topped up if the domestic amount were less than the prevailing EUA prices. This makes it difficult to argue that is not the EU is not going to be collecting charges for business activity in other countries, therefore it is quite similar to the precedent case of intercontinental aviation being included in the EU ETS. For this reason, it is not possible to conclude yet that a sovereignty impact can be avoided.	0	There is insufficient information available about how the US would apply the GSAA to make firm conclusions about whether it will be collecting charges for business activity in other countries. For the time being, a federal cap and trade program is highly unlikely. As the Inflation Reduction Act is quite clearly a subsidy program that could always be increased in future, there is little to suggest yet that the US intends to impact other countries' sovereignty.	1
Total			2		2

steel in the European Union and United States that would warrant action on border carbon mechanisms?

The results of the longitudinal study indicate that, in the EU, a trend has emerged over the 10 year period (2012-21) that transformed the economic area from being a steel exporter to a net importer. While there had been no discernible fall in domestic steel production during the timeframe, imports have filled most of the gap between production and apparent consumption. This provides a counterpoint to the analysis of Grubb et al. (2022) and Eskander and Fankhauser (2023). Further research could be done to explore the specific sources of the imports as a means of validating the findings of Böning et al. (2023), which would be useful to further test applicability of the Porter Hypothesis. It may be that flexing production levels in different regions to arbitrage carbon constraints in different regions is a form of corporate innovation, though not likely to be the kind originally intended by Porter and Linde (1995).

The US was a net importer of finished steel during the entire period

analysed, which, unlike the EU, was relatively stable. Importing steel is not a bad thing in and of itself, as it is likely to be a reflection of efficiency in the allocation of resources. The US has also shown improvements in the emission intensity of steel production over the timeframe, though it is unlikely that the driver of the efficiency gains is the presence of a carbon constraint given the US does not have a federal carbon price in place. This is not enough to say that the Porter Hypothesis does not apply, rather it is necessary to examine other environmental regulations – or expectations of regulations coming in the future – that may be influencing innovation in the US.

The second research question was: What are the specific areas in which border carbon mechanisms are vulnerable to challenge in the future?

While the focus of scholarly analysis has primarily been on consistency with WTO rules (Bellora and Fontagné, 2022; Leonelli, 2022a), this study illustrates that there is a material similarity between border carbon mechanisms and the sovereignty impacts that eventually led to the removal of intercontinental aviation from the EU ETS. This supports the findings of Sapir and Bruegel (2020).

This is not to say that CBAM will be challenged on this basis, though the mechanism is still early in its development process and formal positions of all other countries have not yet been fully revealed. The intercontinental aviation provisions in the EU ETS were legislated in 2008, brought into operation in 2012 though not removed until a few years later. The issue of sovereignty in climate policy has become arguably more accentuated since then, as the Paris Agreement of the UNFCCC made in 2015 moved away from the *top-down* approach of the Kyoto Protocol to the *bottom-up* development of nationally determined contributions (NDC) by countries.

There is still time for reactions to be developed in third countries. If the intercontinental aviation precedent does eventually arise in respect of CBAM, it raises the question of how concerns could be solved. This may shift focus back to carved-out global sectoral agreements - once popular among scholars (Bodansky, 2007; Ellis et al., 2009) - for industries like steel production, noting that the eventual solution to intercontinental aviation was the development of a global sectoral agreement in the form of CORSIA. Intercontinental aviation was, by design, therefore carved out from the overall coverage of the Paris Agreement.

This study illustrates that international trade approaches have not yet settled on how to integrate climate policy imperatives, extending the findings of Horn and Sapir (2013) and Meyer and Tucker (2022). There is an inherent contradiction between the principles of most favoured nation (WTO) and common but differentiated responsibilities (UNFCCC), which is a tension that is not yet resolved. Whether or not border carbon measures induce a flashpoint for resolution of this contradiction depends somewhat on what is at stake. For intercontinental aviation in the EU ETS, countervailing measures that could impact sales of Airbus planes were critical to creating the political appetite for *stopping the clock* (Sheahan and Bryan, 2012). It is not yet clear whether an equivalent countervailing measure as it relates to steel production exists, or whether there is yet a political appetite in third countries to mobilise it.

5. Conclusion

This paper provides a commentary on EU steel production sector and its greenhouse gas intensity during the period 2012-21 where the EU ETS had been in full operation. It also illustrates the broader areas in which border carbon mechanisms, which are now being seriously considered for implementation in several countries and trading blocks, will likely be scrutinised. This broader set of considerations includes consistency with multilateral climate agreements, environmental integrity and sovereignty impacts are taken into account alongside consistency with WTO rules.

As the global consensus moves more rapidly towards an objective of decarbonisation, free allocation practices and green subsidy programs to protect emission intensive and trade exposed industries like steel production from carbon leakage risks will come under more and more scrutiny for their appropriateness. Considering the precedent case of the coverage of intercontinental aviation within the EU ETS, this study illustrates that there is potential for border carbon mechanisms - and other policies that aim to support industrial decarbonisation - to merge with global sector agreements.

Amidst all of this, most technologies needed for decarbonisation face viability challenges. Policy solutions therefore need to find a balance between providing incentives for innovation and visibility of market demand, while at the same time safeguarding against the non-zero risks of carbon leakage.

CRediT authorship contribution statement

Daniel Rossetto: Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no actual or potential competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.horiz.2023.100053.

References

Inflation Reduction Act. (2022) United States of America, Senate and House of Representatives of the United States of America in Congress.
Australian Government, 2023. Safeguard mechanism reforms: Position paper. Department of Climate Change Energy the Environment and Water. Commonwealth of Australia, Canberra.
Bellora, C., Fontagné, L., 2022. EU in Search of a WTO-Compatible Carbon Border Adjustment Mechanism. Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), Paris.
Bloomberg New Energy Finance, 2023. New energy outlook: Industry. New Energy Outlook Series. Bloomberg New Energy Finance, New York.
Bodansky, D., 2007. In: International sectoral agreements in a post-2012 climate framework. Working Paper. Washington DC. Pew Centre on Global Climate Change.
Böning, J., Di Nino, V., Folger, T., 2023. Benefits and costs of the ETS in the EU, a lesson learned for the CBAM design. In: ECB Working Paper No. 2023/2764. Frankfurt, European Central Bank (ECB).
Cooper, D.R., Ryan, N.A., Syndergaard, K., Zhu, Y., 2020. The potential for material circularity and independence in the U.S. steel sector. Journal of industrial ecology 24 (4), 748–762.
Cosbey, A., Droege, S., Fischer, C., Munnings, C., 2019. Developing Guidance for Implementing Border Carbon Adjustments: Lessons, Cautions, and Research Needs from the Literature. Review of environmental economics and policy 13 (1), 3–22.
Cunningham, M., Uffelen, L.V., Chambers, M., 2019. The Changing Global Market for Australian Coal. Reserve Bank of Australia Bulletin - September 2019 28–39.
Della Vigna, M., Stavrinou, Z., Gandolfi, A., Snowdon, N., Young, P., 2021. Carbonomics: Introducing the GS net zero carbon models and sector frameworks. Goldman Sachs Investment Research, London. Goldman Sachs Investment Research.
Edelstein, D., 2022. Rousseau, Bodin, and the Medieval Corporatist Origins of Popular Sovereignty. Political theory 50 (1), 142–168.
Ellis, J., Baron, R., Buchner, B., 2009. Sectoral approaches and the carbon market. OECD Publishing.
Eskander, S., Fankhauser, S., 2023. The impact of climate legislation on trade-related carbon emissions 1996–2018. Environment and Resource Economics.
Eurofer. (2020). "Eurofer statistical definitions." Eurofer Statistics Retrieved 2 March 2023, from https://www.eurofer.eu/statistics/about-eurofer-statistics/eurofer-statistics-definitions/.
European Commission, 2008. Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. Official Journal of the European Union. European Commission.
European Commission (2019). The European Green Deal. European Commission. Brussels. Communication from the Commission to the European Parliament, the

European Council, the Council, the European Economic and Social Committee and the Committee of the Regions.
European Commission, 2021a. Commission implementing regulation (EU) 2021/447 determining revised benchmark values for free allocation of emission allowances for the period from 2021 to 2025 pursuant to Article 10a(2) of Directive 2003/87/EC of the European Parliament and of the Council. (EU) 2021/447. European Commission.
European Commission, 2021b. Proposal for a regulation of the European Parliament and of the Council establishing a carbon border adjustment mechanism. European Union, European Commission. COM (2021) 564 final.
European Environment Agency, 2021. Annual European Union greenhouse gas inventory 1990–2019 and inventory report 2021. Copenhagen, European Environment Agency.
Geels, F.W., Gregory, J., 2023. Low-carbon reorientation in a declining industry? A longitudinal analysis of coevolving contexts and company strategies in the UK steel industry (1988–2022). Energy research & social science 96, 102953.
Goodman, R., Jinks, D., 2003. Toward an Institutional Theory of Sovereignty. Stanford law review 55 (5), 1749–1788.
Grubb, M., Jordan, N.D., Hertwich, E., Neuhoff, K., Das, K., Bandyopadhyay, K.R., van Asselt, H., Sato, M., Wang, R., Pizer, W.A., Oh, H., 2022. Carbon Leakage, Consumption, and Trade. Annual review of environment and resources 47 (1), 753–795.
Gupta, S., 2020. Industry Address. LME Metals Seminar. London Metal Exchange, London.
Hogan Lovells. (2023). "The IRA: What's in it for manufacturers?".
Horn, H., Sapir, A., 2013. Can border carbon taxes fit into the global trade regime? Federal Reserve Bank of St Louis, St. Louis.
Horngren, T., Leach, T., Maxwell, R., Graham, P., Kelly, R., Turner, K., Malos, A., 2023. Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net zero global economy. Climate Works Centre, Monash University & Climate KIC Australia, Melbourne.
Howe, J., Sutter, P., 2017. Making climate change history: Documents from global warming's past. University of Washington Press, Washington DC.
International Carbon Action Partnership. (2022). "EU Emissions Trading System (EU ETS)." Fact Sheet Retrieved 26 September 2022, from https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-43.pdf.
Keen, M., Parry, I., Roaf, J., 2022. Border carbon adjustments: rationale, design and impact. Fiscal studies 43 (3), 209–234.
Kurtulus, E., 2005. Theories of Sovereignty: Reclaiming the Domain of Empirical Research. Palgrave Macmillan US, United States.
Leonelli, G.C., 2022a. Carbon Border Measures, Environmental Effectiveness and WTO Law Compatibility: Is There a Way Forward for the Steel and Aluminium Climate Club? World trade review 21 (5), 619–632.
Leonelli, G.C., 2022b. Practical obstacles and structural legal constraints in the adoption of 'defensive' policies: comparing the EU Carbon Border Adjustment Mechanism and the US Proposal for a Border Carbon Adjustment. Legal Studies 42, 696–714, 2022.
Lisowski, M., 2002. Playing the two-level game: US president Bush's decision to repudiate the Kyoto Protocol. Environmental politics 11 (4), 101–119.
Maat, E.P., 2022. Leading by Example, Ideas or Coercion? The Carbon Border Adjustment Mechanism as a Case of Hybrid EU Climate Leadership. European Papers 7 (1), 55–67, 2022.
Mehling, M.A., van Asselt, H., Das, K., Droege, S., Verkuijl, C., 2019. Designing Border Carbon Adjustments for Enhanced Climate Action. The American journal of international law 113 (3), 433–481.
Meyer, T., Tucker, T.N., 2022. Trade and Climate, Law and Politics: A Response. World trade review 21 (1), 127–129.
Muslemani, H., Liang, X., Kaesehage, K., Ascui, F., Wilson, J., 2021. Opportunities and challenges for decarbonizing steel production by creating markets for 'green steel' products. Journal of cleaner production 315, 128127.
Overland, I., Sabyrbekov, R., 2022. Know your opponent: Which countries might fight the European carbon border adjustment mechanism? Energy policy 169, 113175.
Pirlot, A., 2017. Environmental Border Tax Adjustments and International Trade Law: Fostering Environmental Protection. Edward Elgar Publishing, Cheltenham.
Poljak, V., Tran, J., 2023. Debelle bemoans distortion created by Biden's $US1trn green bill. Australian Financial Review. Nine Entertainment Company, Sydney.
Porter, M.E., Linde, C.v.d., 1995. Toward a New Conception of the Environment-Competitiveness Relationship. The Journal of economic perspectives 9 (4), 97–118.
Rossetto, D., 2023. The Carbon Border Adjustment Mechanism: What does it mean for steel recycling? Sustainable Horizons 5, 100048, 2023.
Russian Aviation (2012). "Joint declaration of the Moscow meeting on inclusion of international civil aviation in the EU-ETS".
Sandbag (2022). "European scrap steel floats away under carbon market incentives." https://sandbag.be/index.php/2022/09/22/european-scrap-steel-floats-away-under-carbon-market-incentives/2022.
Sapir, A. and H. H. Bruegel (2020). Political assessment of possible reactions of EU main trading partners to EU border carbon measures. Brussels.
Shao, S., Hu, Z., Cao, J., Yang, L., Guan, D., 2020. Environmental Regulation and Enterprise Innovation: A Review. Business strategy and the environment 29 (3), 1465–1478.
Sheahan, M., Bryan, V., 2012. Airbus ministers seek suspension of EU emissions plan. Reuters. Thomson Reuters, London.
Shen, H., Yang, Q., Luo, L., Huang, N., 2023. Market reactions to a cross-border carbon policy: Evidence from listed Chinese companies. The British accounting review 55 (1), 101116.
Singh, S., 2022. Tracing the "Common but Differentiated Responsibilities" (CBDR) principle under climate change regime. Indian Journal of Law and Justice 13, 251–272. No. 02 - September 2022.
Tucker, T. N. and T. Meyer (2021). A Green steel deal: Toward pro-jobs, pro-climate transatlantic cooperation on carbon border measures. Working Paper. New York, Roosevelt Institute.
United Nations, 1992. UN Framework Convention on Climate Change. U. Nations. UNFCCC Secretariat, Bonn.
US Environment Protection Agency, 2023. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2021. US Environment Protection Agency, Washington DC.
Weijers, D., Eng, D., Das, R., 2010. Sharing the responsibility of dealing with climate change: Interpreting the principle of common but differentiated responsibilities. ANU E Press, p. 141.
White House (2021). FACT SHEET: The United States and European Union To Negotiate World's First Carbon-Based Sectoral Arrangement on Steel and Aluminum Trade. Joint US-EU statement on Trade in Steel and Aluminium,. Government of the United States of America.
Wood, T., Dundas, G., Ha, J., 2020. Start with Steel. Grattan Institute, Melbourne, Australia.
World Bank, 2022. State and trends of carbon pricing 2022. The World Bank Group, Washington DC.
World Steel, 2012. Sustainable Steel at the Core of a Green Economy. World Steel Association.

Daniel Rossetto is a world-leading specialist in green finance, climate risk management, clean energy development and finance, low-carbon transition strategy and carbon markets with over 20 years of professional experience. He regularly consults to major corporations and investment managers on developments in carbon markets and the economics of low-carbon technologies. He has authored several practitioner papers on green finance and climate-themed bonds published on Bloomberg platforms and journal papers on topics related to emissions trading and international trade. Daniel is currently completing his doctorate at The University of Adelaide.Daniel has served as a company director in the United Kingdom for over a decade with Climate Mundial Limited. Prior to Climate Mundial, Daniel held the position of Executive Director at J.P. Morgan Chase. He joined J.P. Morgan as the firm commenced build out of its global environmental markets, carbon finance and carbon trading business, covering major compliance-driven emissions trading markets such as the European Union Emissions Trading System (EU ETS), the New Zealand ETS and California ETS. During his time at J.P. Morgan, Daniel was responsible for sales, origination and risk management and delivered some of the most important structured emissions transactions – linked to energy, agricultural & metals commodities - across the major market countries and regions.Prior to joining J.P. Morgan, Daniel played an integral role in the developing the Enel Group's carbon strategy while employed at the firm's head offices in Rome. The strategy was designed primarily to ensure the firm's compliance with the EU ETS as well as the potential for international business units to generate compliance grade carbon credits. This incorporated emissions reporting, determining free allocations and sourcing of project-based credits via the Kyoto Protocol flexibility mechanisms - the Clean Development Mechanism (CDM) and joint implementation (JI). During the period 2000-05, Daniel was a policy maker in Australia and was a member of the National Emissions Trading Taskforce (NETT) tasked with designing a national market-based program for reducing emissions across the electricity generation, industry and transportation sectors. He was also a member of the COAG senior officials working group that developed the first version of the National Greenhouse and Energy Reporting (NGER) framework. Daniel has worked extensively across the world including in Australia, Europe, Africa, Middle-East, countries of the FSU, Latin America and Asia. He speaks five languages fluently.

Chapter 7. Publication three and statement of authorship

This section presents the publication: *Relationships between sustainability disclosure, environmental innovation and performance: An examination of practice within the Australian construction and demolition waste sector*.

7.1 Statement of authorship

The statement of authorship is provided below in Table 10.

Table 10 – Statement of authorship for publication three

Title of paper:	**Relationships between sustainability disclosure, environmental innovation and performance: An examination of practice within the Australian construction and demolition waste sector.**			
Publication status:	Published	×	Accepted for publication	
	Submitted for publication		Unpublished and unsubmitted work written in manuscript style	
Publication details:	Rossetto, D. (2023). "Relationships between sustainability disclosure, environmental innovation and performance: An examination of practice within the Australian construction and demolition waste sector". Environment, Development and Sustainability. DOI: 10.1007/s10668-023-04291-w Reproduced in accordance with the publishing agreement.			
Name of principal author:	Daniel Marc Rossetto			
Contribution to the paper:	Research design, research execution and sole author			
Overall percentage:	100%			
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.			
Signature:				
Date:	14/03/2024			

7.2 Specific aims of the paper

The specific aim of this paper was to assess the effectiveness of voluntary action by firms to address externalities generated within the construction and demolition waste ecosystem. In doing so, the paper addresses the research project's third objective to: *Assess the effectiveness of voluntary action by firms to address externalities generated within the construction and demolition waste ecosystem*.

This paper explored disclosures and environmental impact mitigation practices across the Australian construction and demolition waste ecosystem. It uses a combination of interviews and longitudinal analysis of financial reports and sustainability disclosures to explore the connection between disclosure practice and environmental innovation. It revealed that there is a connection between responsive disclosure by firms and their innovation activity. If innovation is designed to obtain a competitive advantage, it follows that boundaries will be placed around external distribution of information.

The paper concluded that stakeholders, including customers, financiers, investors, governments and broader society, can have a reasonable degree of confidence in external communication on sustainability matters by firms, though it is important that these stakeholders acknowledge such reporting has limits. The paper highlighted that there may be some areas of externality generation by firms that require coordinated stakeholder demand and even regulatory support to specify that disclosure takes place and to ensure comparability of outcomes. This would lead to a reduction in instances of greenwashing.

7.3 Current citations

The paper was published in December 2023, so there are no citations to report.

7.4 Publication three

The paper in its current form is now included.

Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-04291-w

Relationships between sustainability disclosure, environmental innovation and performance: an examination of practice within the Australian construction and demolition waste sector

Daniel Rossetto[1]

Received: 20 December 2022 / Accepted: 27 November 2023

Abstract
Growth in sustainability reporting and disclosure by corporations have led to questions about how representative such information is of the real environmental performance of firms. There is doubt about whether disclosure has any effect on management and operational practice. Some scholars suggest sustainability claims are exaggerated or inaccurate, leading to broader concern about a phenomenon called *greenwashing*. This causes uncertainty among stakeholders about the impact firms have on the environment, and what they are doing about mitigating impacts and capitalising on opportunities. This paper explores disclosures and environmental impact mitigation practices across the Australian construction and demolition (C&D) waste ecosystem. It uses a combination of practitioner interviews and longitudinal analysis, evaluating financial reports and sustainability disclosures to explore the connection between disclosure practice and environmental innovation. It reveals that, if the purpose of innovation is to confer a competitive advantage, sometimes known as strategic corporate social responsibility (CSR), there is an incentive for firms to limit external distribution of such information. The paper therefore provides a new and interesting insight into the behaviour of firms. Whereas previously, concerns over greenwashing suggest that firms exaggerate sustainability performance, this paper reports evidence that much innovation remains confidential. If, as the Port Hypothesis would suggest, firms are innovating in response to higher environmental standards, there is a natural incentive to delay external communication until new products can be sold in the marketplace. There are implications for policymakers considering if and how to regulate sustainability disclosure, and for managers seeking to improve sustainability communication with stakeholders.

Keywords Environmental externalities · Construction and demolition (C&D) waste · Corporate social responsibility (CSR) · Sustainability reporting · Greenwashing · Innovation

✉ Daniel Rossetto
daniel.rossetto@adelaide.edu.au

[1] School of Architecture and Civil Engineering, Faculty of Sciences, Engineering and Technology, The University of Adelaide, Room 3009, Horace Lamb, North Terrace, Adelaide, SA 5005, Australia

Published online: 15 December 2023

1 Introduction

Corporate social responsibility (CSR) practices in firms have been increasing over the last few decades coinciding with growth in sustainability reporting and disclosure activity (Fatima & Elbanna, 2022; Robins, 2005). At first glance, this suggests that firms are now working to make the world a better place—and are doing so on a voluntary basis. However, one might ask whether firms are truly able to change business practices that lead to negative environmental and social impacts, or how reliable external communications are at providing a real assessment of the contribution that voluntary corporate action is making.

Porter and Kramer (2006) held that CSR, despite undertones suggesting it is primarily about societal welfare, can impact the competitiveness of firms. Accordingly, the scholars categorised actions into two groups. The first is what was termed *responsive CSR* and the other *strategic CSR*. Some actions will be the direct result of an expectation arising outside the firm—from customers, societal stakeholders, financiers, investors and even government—that something be done about a given issue. This kind of action is referred to as responsive CSR. Actions may also arise due to specific advantages a firm might gain from them, such as lower operating costs from greater efficiency. This kind of action is strategic CSR.

If one accepts the Porter and Kramer (2006) notions of difference between responsive and strategic CSR, it is not surprising that external communications have become embroiled in questions about authenticity. Recent years have seen the rise of perceptions of greenwashing (Coen et al., 2022). Soh Young and Schumacher (2021) and de Silva Lokuwaduge and De Silva (2022) reported that there is an incentive for firms to selectively publish material about operational performance that does not comprehensively describe impacts on the environment, and in some cases there may even be an incentive to misrepresent these elements. So conspicuous have these kinds of external communications by firms about sustainability achievement become that regulatory bodies are now introducing guidance on what constitutes misrepresentation (European Commission, 2023; Financial Conduct Authority, 2022). There is an acknowledged risk that allowing firms to report and communicate externally without any regulations may lead to misrepresentations about corporate performance and risk. Indeed, Chen et al. (2018) found there may even be benefits for firms in being the subject of mandated sustainability standards and reporting. This is because the mandatory nature of disclosure removes some of the discretion from its disclosure and provides a basis for firms to focus activities.

Notwithstanding, other studies suggest that firms may, in fact, be protecting certain information about their sustainability and CSR achievement from public communication. Unerman et al. (2018) noted that some of this non-disclosure may arise due to barriers within firms prevent efficient communication between those preparing sustainability information with those responsible for operational management. Zharfpeykan and Akroyd (2022) noted that what firms decide to include in external communications has little if any influence over a company's management system. Al Hawaj and Buallay (2022) found that the impact of what firms report on sustainability activities on operational performance, with respect to financial metrics like equity returns and returns on assets, varies according to the sector of operation. What has not yet been considered in depth is the possibility that the information that is not being reported externally may relate to product development or innovation. It may relate to the competitive positioning of firms and is therefore not for public disclosure.

It is in this context that the exploratory research presented in this article has been undertaken. Some of the open questions for consideration in this paper are: How representative are external reports of the efforts firms are investing to reduce environmental impact? Are there strategic reasons why firms might not disclose certain information about their operations when it comes to environmental impact? What does this tell us about the confidence that customers, societal stakeholders, financiers, investors and even governments can have on external communication by those firms?

On scope, it would be too ambitious an undertaking to explore these issues for every firm, in every location and operating in every industry. The research described in this paper was focused on the construction and demolition waste sector. Hoornweg et al. (2013), Pickin et al. (2020) and Kabirifar et al. (2021) found the sector can contribute as much as 40% of total waste generated globally as well as a disproportionately high amount of waste being sent to landfills, which leads to environmental damage and risks to human health. It focuses on the construction and demolition waste ecosystem—being the network of organisations performing the different functions such as raw material and energy supply, manufacture, design and construction, waste management, importing and exporting—in Australia.

2 Literature review

The study begins with a review of literature in areas key to the study, which are environmental externalities, construction and demolition waste management, corporate social responsibility, sustainability reporting and theories of green innovation. Literature was searched on databases such as Google Scholar using keywords such as 'C&D waste', 'environmental externalities', 'corporate social responsibility', 'sustainability reporting' and 'corporate innovation'. Industry literature was identified using other, non-academic search engines using the same key words, as well as other financial markets and trade media sources.

2.1 Environmental externalities

Environmental impacts that arise from business activities are what economists describe as externalities. Laffont (2008) and Helbling (2020) describe negative externalities as costs to one or more individuals within a society brought about by production activity for which the private interest does not pay. Di Foggia and Beccarello (2022), Austin and Rahman (2022) and Chioatto and Sospiro (2023) also used the term market failure to describe externalities, which are instances where the full costs of production are not included in private production decisions leading to inefficient allocation of resources across a society.

Coase (1960) and later Mirdar Harijani and Mansour (2022) referred to negative externalities as a social cost. An example of an externality would be pollution generated by a private factory and discharged into a river, where the pollution then negatively impacts the livelihood of farmers downstream who use the same river for agricultural activities. If the pollution reduces the farmers' ability to produce, the negative externality could be quantified as the loss in production for the farmers directly attributable to the factory's pollution.

Similarly, it is possible for an externality to be positive, in which case it refers to a benefit to society brought about by private production activity for which society does not pay. An example of a positive externality may arise where a business generates employment,

whereby the new people obtaining a job at the business would otherwise have received publicly funded social security.

Friedman (1970) originally asserted that firms were not naturally incentivised to internalise the costs of externalities. Coase (1988) suggested that the best way to alter the behaviour of firms is to make it in their interest to do so. Mazzucato and Ryan-Collins (2022) outlined some of the methods at the disposal of public policy makers to correct for the market failures, on the assumption that firms did not have an incentive to address externalities. Robins (2005), Porter and Kramer (2006) and Tao et al. (2022) outlined the case for voluntary implementation of voluntary action by firms, arguing that creating positive environmental and social impacts can lead to competitive advantages.

Fatima and Elbanna (2022) noted that voluntary action by firms to address negative environmental externalities was often preceded by stakeholder pressure. Indeed, the country in which a firm's operations are located can affect the nature of stakeholder pressure that later becomes the driver of innovation and organisational change.

2.2 Construction and demolition waste

Construction and demolition (C&D) waste management as an area of business activity that can lead to the generation of significant environmental and social externalities (Benachio et al., 2020; Shooshtarian et al., 2020). C&D waste contributes a relatively large percentage of overall waste production and remains a significant overall component of overall waste discharges to landfill across the world. According to the United Nations Environment Programme (2015), as many as 10 billion tonnes of waste is generated every year. Hoornweg et al. (2013) noted that as much of 40% of total waste is generated by or connected to C&D activity.

Recent studies from around the world have considered the externalities generated by the C&D waste ecosystem. In the Emilia-Romagna region in Italy, Magrini et al. (2022) found that the main negative externalities associated with waste management practice were those connected to transport, with relatively smaller contributions from landfilling and incineration. Table 1 provides a summary of the indicative environmental externalities, both positive and negative, arising as a result of circular C&D waste management practice.

Iodice et al. (2021) studied C&D waste in the Campania region of Italy and identified a number of positive externalities such as job creation and benefits associated with land

Table 1 Summary of the environmental externalities arising across the C&D waste ecosystem

Operational area	Positive	Negative
1. Transport	Not applicable	Air pollution Noise Greenhouse gas emissions
2. Treatment plants (processing)	Waste to energy utilisation	Air pollution Noise Leachate and groundwater Greenhouse gas emissions
3. Recycling materials	Savings of primary materials Avoided greenhouse gases Avoided environmental damage	Not applicable

Source: Adapted from Magrini et al. (2022)

use. However, the authors found that direct economic costs mean that implementation is likely to be hindered. In other words, market failures may exist. The authors concluded that this supports the argument for more incentives to promote environmentally sound C&D waste management. Aldieri et al., (2021a, 2021b) identified the need for eco-efficiency as a strong incentive for action by private firms and the development of new circular business models.

Pickin et al. (2020), in the National Waste Report, observed a similar trend in Australia, where waste connected to C&D activity is estimated to be 44% of the national total. C&D waste is notable because a disproportionate amount is sent to landfill, which Kabirifar et al. (2021) reported is around 35–40%. Thomson (2021) estimated that waste remediation and materials recovery activity across Australia was worth around AUD 5 billion per year. The ecosystem is influenced by a range of policies, regulations and programmes designed and implemented by public administrators and policy makers. The ecosystem also serves other sectors, particularly in the areas of waste remediation and resource recovery (Clean Energy Finance Corporation & Arup, 2021; Pickin et al., 2020).

These studies are helpful in identifying some of the potential externalities, both positive and negative, created by or connected to C&D waste activity. There is opportunity for deeper research to connect the externalities to the operations of specific corporations and business entities, as well as contribution of voluntary activity towards addressing externalities associated with waste.

2.3 Sustainability reporting

Disclosure by firms of their activities to address externalities falls within the practice of sustainability reporting. Unerman et al. (2018) noted that it is generally kept as a distinct exercise and is not integrated with financial reporting, very often managed by different groups of people in organisations. As the practice has become increasingly popular, Horn et al. (2022) and Pizzi et al. (2022) noted a proliferation in reporting standards and approaches such as the Sustainability Accounting Standards Board (SASB) and the Global Reporting Initiative (GRI). A key concept within standards is that of *materiality*, which sets out the basis on which a firm may decide upon what information to include in its reporting and what to disclose. Firms have a choice about what information to disclose, which may include any externalities caused or from which they benefit.

SASB adopts an approach similar to that used in financial accounting in which materiality relates to information that, if it were known, would likely influence investment or lending decisions by third parties. In this context, if an externality has the potential to impact the profitability of a firm or could create a liability for the organisation, it may be considered material. This can be considered the *financial materiality* track. The GRI, on the other hand, takes a more general view, considering instead that materiality refers to a firm's impacts on the environment or the societies within which it operates. This may be called the *impact materiality* track and would include items like energy and water use, waste production, human rights, engagement with local stakeholders and contribution to climate change, among other things.

Jørgensen et al. (2022) noted that in both cases the users of the information may be different. For example, financially material information may be used by an investor or a lender, whereas impact information might be used by customers, prospective employees and other stakeholders. In some cases, the difference in information disclosed can lead to vastly different impressions of a firm. Delgado-Ceballos et al. (2023) highlighted the importance,

therefore, of a new term known as *double materiality* to draw a link between what firms do and their contribution to society-wide sustainable development goals, drawing a clearer distinction between materiality for financial reporting purposes and sustainability.

O'Dwyer and Unerman (2020) observed that there was a shift occurring in some stakeholders' interests in sustainability reporting, particularly as financiers, investors, capital market participants and financial regulators become interested in the risks posed by some areas of environmental impact. An initiative known as the Taskforce for Climate-Related Financial Disclosure (TCFD) a relatively recent initiative promoted by central banks around the world, was cited as an example. TCFD guidelines will help stakeholders to gain a view of the future risks faced by entities resulting from exposure to future pricing of climate externalities. TCFD encourages firms to consider broader supply chain impacts, including not only greenhouse gas emissions directly under the operational control of the firm (scope one), but also those arising from a firm's consumption (scope two) or supply chain (scope three). TCFD also introduces the link to disclosure of contingent liabilities—liabilities that have not yet arisen but may in the future and that may result in a cost to the firm—is also of relevance. This might include a future liability to pay for greenhouse gas emissions that, today, is not a legal requirement. Lykkesfeldt and Kjaergaard (2022) found this kind of information had the potential to impact the cost of capital to firms, which is a factor of competitiveness. Lenders to firms may increase the interest margins charged on loans to firms with higher risk linked to environmental impacts.

Sustainability reporting remains a largely voluntary activity for firms in most parts of the world though there are some exceptions. Whether disclosure of impacts or risks acts as an incentive to take action remains a topic of investigation. Chen et al. (2018) noted that mandatory disclosure impacts firm performance, because there is additional scrutiny and that creates a pressure to act. Zharfpeykan and Akroyd (2022) found that sustainability remained largely disconnected from regular management of companies and therefore little evidence existed to suggest the practice of disclosure was impacting corporate strategy or results.

2.4 Corporate social responsibility

Corporate social responsibility (CSR) is an area of practice concerned with the contribution firms make to societal welfare. It recognises that firms are interested in contributing to the communities and stakeholders in the markets in which they operate (Delgado-Ceballos et al., 2023). CSR has also been questioned. Former professor of economics at the University of Chicago, Milton Friedman (1970), when writing in the New York Times, famously argued that the only corporate social responsibility of firms was to increase its profits for shareholders. He had highlighted that many firms delegate decision-making to executives, who are therefore acting as agents rather than as principals. In such cases, executives engaging in CSR are at risk of making decisions to forego profit for the shareholders. Friedman argued that shareholders could make their own decisions to invest their profits into such activities and did not need corporate managers to do this for them. Shaikh et al. (2022) suggested that CSR was important, notwithstanding, to engaging managers, who are able to deliver an organisational commitment to contributing to the social good.

Latapí Agudelo et al. (2019) explored the extent to which CSR activity is driven by societal expectations and noted that firms are motivated by a notion called a *social license to operate*. That is, a firm's reputation within the jurisdictions and communities where it operates may motivate it to take certain CSR activities. Porter and

Kramer (2006) noted that CSR was not entirely altruistic or responsive only to societal stakeholders. As mentioned already in Sect. 1, created a distinction between CSR that responds to external stakeholder demand (societal CSR) and that which can be deployed to create a genuine competitive advantage for a firm (strategic CSR). If one considers the work of authors like Porter and Kramer (2006) and Latapí Agudelo et al. (2019), it is possible to see that strategic CSR is not entirely different to that which was advocated by Friedman (1970). Indeed, if financiers may increase the cost of loans to firms on the basis of environmental risks—like one sees in the climate-related initiatives such as the TCFD—as considered by O'Dwyer and Unerman (2020) and Lykkesfeldt and Kjaergaard (2022), this might make a firm less competitive. A case then begins to emerge whereby even some forms of responsive CSR appear less altruistic.

2.5 Theories of corporate innovation

The final strand of literature relates to innovation theory within firms. This is a vital strand because it will help to analyse the extent to which disclosure and reporting of externalities, positive and negative, is a real driver of innovation and changes in business practice. One of the most important theories in this regard is the *Porter Hypothesis* (Porter, 1990), which asserts that achieving higher environmental standards leads to innovation and ultimately enhanced competitiveness of firms.

This is aligned to the *Theory of Creative Destruction and the Business Cycle* (Parker, 2012; Schumpeter, 1939), which suggests that innovation comes during disruptive times when the profitability of firms is threatened. The threat may come through downturns in the business cycle, or through endogenous shocks—including but not limited to introduction of new environmental standards by regulations—that, without any kind of innovation, may cause a firm to no longer be viable. Hamrouni et al. (2021) highlighted the importance of case-based reasoning as a driver of innovation. Firms may respond if there is a deemed pay-off for innovation even if it comes with risk. Aldieri et al. (2021a, 2021b) also noted that threats to business outlook motivate action.

A key question connected to this research project is therefore whether firms stand to gain, strategically, from publicly disclosing or communicating their innovation and, if so, when. For example, if a firm within the construction and demolition waste ecosystem in Australia had discovered a way to reduce its waste or process waste in a way that increased its competitiveness—and therefore constituted a *trade secret*—would it wish to communicate that publicly? Lemley (2008) noted that trade secrets are not the same as *intellectual property rights*; therefore, if details about how the firm was processing or utilising waste became broadly known, how would the firm protect its competitive advantage and prevent others from adopting a similar approach? Conversely, is there anything about the method of processing or utilising waste that is the subject of the trade secret which, if known to customers, would enable to firm to increase sales? Equally, what is the connection between the information that a firm chooses to publish, or is compelled to publish, in its sustainability reporting, or that its stakeholders—which may be its customers, regulators, investors or its financiers—wish to know and either of (a) the way a firm seeks to innovate in respect of its environmental performance or (b) its returns on equity or overall financial performance?

3 Research methodology

The aim of this paper is to investigate the questions as set out in Sect. 1: How representative are external reports of the efforts firms are investing to reduce environmental impact? Are there strategic reasons why firms might not disclose certain information about their operations when it comes to environmental impact? What does this tell us about the confidence that customers, societal stakeholders, financiers, investors and even governments can have on external communication by those firms? It considers these issues in the context of case studies that examine businesses within the functional areas of the Australian construction and demolition waste ecosystem.

3.1 Research design

In order to achieve the aim of this research project, two different empirical approaches adopted: the first is longitudinal analysis and the second is interviews, in which the units of analysis are firms or organisations participating in the construction and demolition waste ecosystem. To ensure that the full ecosystem was represented, organisations were selected to cover five main functional areas of the ecosystem as follows: (1) raw material feedstocks and inputs, (2) manufacturing, (3) construction and demolition activity, (4) waste management and (5) imports and exports. The ecosystem and functional areas are illustrated in Fig. 1.

The research strategy is illustrated in Fig. 2. Longitudinal analysis was used to objectively establish sustainability and financial reporting practices of the selected organisations. Interviews were chosen in order to identify the kinds of environmental practices being pursued at the operational level and the kinds of barriers that are becoming drivers for corporate innovation.

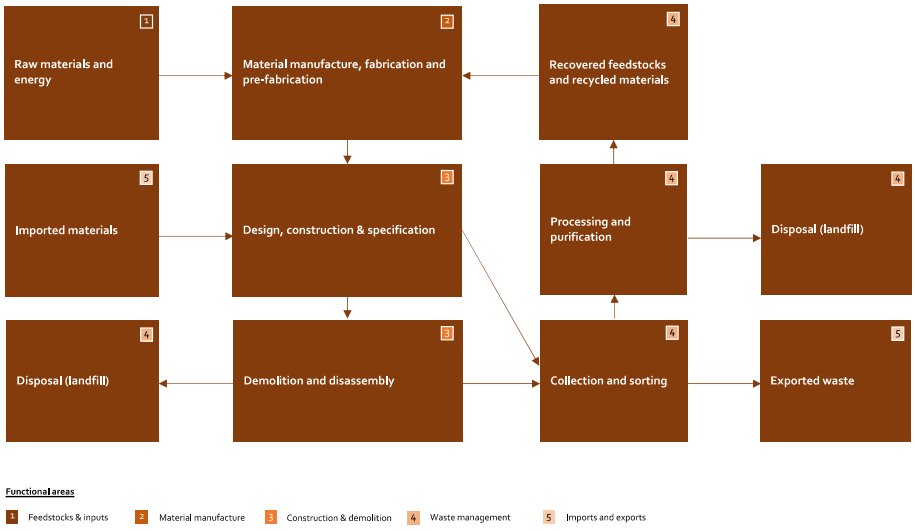


Fig. 1 Functional areas of the construction and demolition waste ecosystem

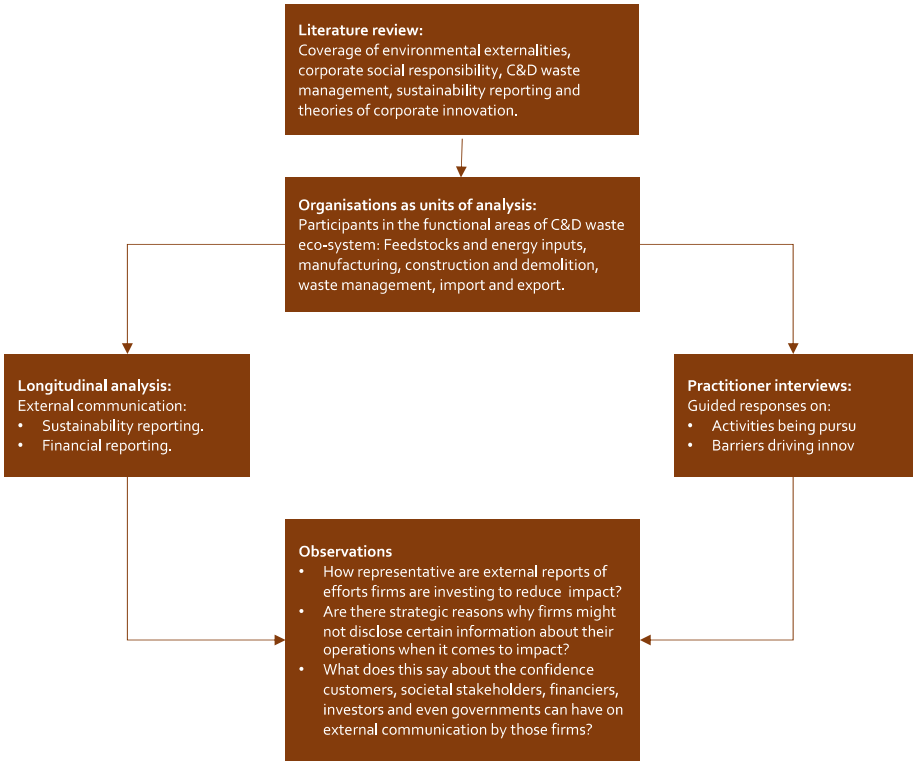


Fig. 2 Diagrammatic representation of the research strategy

At the completion of the longitudinal analysis and interviews, observations were compared with theories of innovation as considered in Sect. 2.5 of the literature review and with respect to the questions posed in the introduction. This allowed for a deductive assessment of the suitability of the theories as explanations for the observations. Sections 3.1.1 and 0 illustrate the approaches adopted for the longitudinal analysis an interviews.

3.1.1 Longitudinal analysis

The analysis involved examination of the annual reports and other corporate documents issued by the organisations analysed such as sustainability reports and other external communications. The reports were examined for data items that corresponded with the six summarised in Table 2.

This includes the organisations' profit and loss, assets, liabilities and shareholders' equity reported in financial statements. This allowed computation of returns on equity, which allows for comparability of analysis undertaken by Al Hawaj and Buallay (2022) and Zharfpeykan and Akroyd (2022). It also allows for comparison with equity capital market indices such as the Australian Stock Exchange (ASX) 200, which Mathews (2019) noted in 2019 was part of a broader equities market that is valued at more than AUD 2 trillion and whose shares traded

Table 2 Summary of the data items reviewed in company documentation as part of the analysis

Data item	Description
Profit and loss	What are the profit and loss results reported in the organisations' audited financial statements?
Balance sheet	What are the assets, liabilities and shareholders' equity reported in the organisations' audited financial statements?
Sustainability standards	Has a standard been used for determining the data to disclose—in particular the Global Reporting Initiative, the Sustainability Accounting Standards Board and the Taskforce on Climate-Related Financial Disclosure, which may be indicators of how it applies materiality?
Externalities (negative)	Is there evidence of some form of disclosure of environmental indicators by the organisation that may be linked to negative externalities such as air pollution, water use and pollution, material consumption and greenhouse gas emissions across scopes one, two and three?
Externalities (positive)	Is the organisation disclosing information about its recycling or resource recovery rates, or the measures it is taking to address those items?
Contingencies	Is there any evidence that externalities are appearing as contingent liabilities (or assets in cases where the externalities were positive), which indicates a potential future impact on the organisation's financial performance?

with a daily value of AUD 5 billion. Sustainability standards applied in determining the extent of reporting, disclosure and areas where externalities might be expected are also examined.

3.1.2 Interviews

Interviews were used to solicit the views of individual executives—in their capacity as agents of organisations being analysed—in order to identify the kinds of environmental innovations and practices were being considered or implemented at the operational level, and compare these to the sustainability-related items being reported by those organisations. Each interviewee was invited to participate on the basis of an interview protocol, which posed a number of questions about areas of environmental impact connected to operations in the construction and demolition waste ecosystem.

Following finalisation of minutes, the contents were coded according to headings that connect the information to the research questions and theories being examined. Coding is a term put forward by Saldaña (2021) to describe the way that qualitative information can be organised for further analysis. These are broad thematic headings that help to identify patterns within the roles and relationships that the qualitative data contain. Yin (2018) suggested that it was important to identify the units of analysis, whereupon the coding can be applied to extract any patters of relevance to the research question posed. Bernard (2018) described coding as a method for linking qualitative information collected from single units, groups, organisations or events. The coding categories or *units of observation* included (1) responsive CSR, (2) strategic CSR, (3) efforts to innovate and (4) connection to sustainability reporting activities.

3.2 Data collection

The C&D waste ecosystem in Australia is a small but emerging sector of economic activity, therefore the sample group available for analysis is limited. In Sect. 2.2, it was shown

that the sector is turning over approximately AUD $5 billion a year—compared to AUD $424.1 billion across the whole construction industry—in Australia. Data collection therefore occurred with a total of eight organisations, as well as for the broader ASX 200 for comparative purposes. The organisations chosen for this study are among the most important operating in the sector, supporting the comprehensiveness of the exploration within the given context. As there are interactions with human participants resulting from the case studies, the participating organisations are anonymised. In order to underwrite the credibility and trustworthiness of the data collected, a number of safeguards were deployed as follows:

Safeguard 1 For the interviews, participants sought were all holders of senior positions within their respective organisations, obtained internal approval to participate and also gained clearance for the contents of the minutes from their firms, leading to highly representative and trustworthy data.

Safeguard 2 Leading organisations within the sector in Australia were considered for the longitudinal analysis which are either firms listed on stock exchanges or state-owned business enterprises. This ensures that the information contained in the company reports is prepared in accordance with nationally and in some cases internationally recognised standards and is either audited or reviewed by a third party assurance provider. The data provide a high level of confirmation and trustworthiness. International standards also mean that there is a reasonable degree of transferability of the findings to jurisdictions other than Australia.

Table 3 summarises the organisations interviewed and notes the functional areas in which each operates. A coding system was developed using the numbers 01–08 for the organisations.

For the longitudinal analysis component, data were obtained for a period of minimum of four years and, where available, for up to six years. A summary of the years for which reporting was reviewed is given in Table 4. The data relate either to financial years, ending on 30 June of the year cited in the title of the report, or to a calendar year from 1 January through to 31 December of a given year. Where a report relates to a year (2018, for example) it may cover a period of 01/01/2018 to 31/12/2018 or to the period 01/07/2017 to 30/06/2018 (inclusive). Equity return data were also collected and processed for the ASX 200 companies. These data allow the comparability of equity returns as well as the standard deviation over the time period. The standard deviation indicates how closely values are related to the mean and serves as a measure of the volatility in the results over time.

For the interview component, questions were designed sufficiently broadly to allow interviewees to express their opinion—or to describe practices—without perceived

Table 3 Organisations selected to participate in the research

Organisation	Functional area	Interview
Organisation 01	1 (feedstock & inputs), 4 (waste management) & 5 (imports & exports)	Yes
Organisation 02	2 (manufacture), 3 (construction & demolition)	Yes
Organisation 03	1 (feedstock & inputs), 4 (waste management) & 5 (imports & exports)	Yes
Organisation 04	1 (feedstock & inputs), 2 (manufacture), 3 (construction & demolition)	Yes
Organisation 05	1 (feedstock & inputs) & 2 (manufacture)	Yes
Organisation 06	4 (waste management)	No
Organisation 07	1 (feedstock & inputs), 4 (waste management) & 5 (imports & exports)	Yes
Organisation 08	4 (waste management)	No

Table 4 Summary of company data reviewed for the analysis

Organisation/year	2016	2017	2018	2019	2020	2021
Organisation 01	Yes	Yes	Yes	Yes	Yes	No
Organisation 02	Yes	Yes	Yes	Yes	Yes	Yes
Organisation 03	Yes	Yes	Yes	Yes	Yes	Yes
Organisation 04	No	No	Yes	Yes	Yes	Yes
Organisation 05	Yes	Yes	Yes	Yes	Yes	Yes
Organisation 06	No	No	Yes	Yes	Yes	Yes
Organisation 07	No	No	Yes	Yes	Yes	Yes
Organisation 08	Yes	Yes	Yes	Yes	Yes	Yes

constraint. This is different from a survey where very specific questions are asked with a view to collecting homogenous responses for further statistical analysis. A representative of each organisation (with the exception of Organisations 06 and 08 who did not participate) was interviewed using three discussion question areas as follows: (1) What is your main interest in C&D waste and why do you believe it is important? (2) What do you consider to be the most important advantages and disadvantages of your organisation's approach to C&D waste management? and (3) Are there any improvements that you would like to suggest, whether they be voluntary, regulatory or other? Formal minutes of each interview were taken and then agreed with participants before contents were finalised. Data were anonymised in accordance with ethics procedures agreed to protect privacy of participants and confidentiality of information shared.

4 Results

The following section presents results of the longitudinal analysis (Sect. 4.1) and the practitioner interviews (Sect. 4.2).

4.1 Results of the longitudinal analysis

The analysis revealed variations across the years of the return on equity for firms across the period 2016-21 and a comparison with the ASX 200 benchmark (Fig. 3 below). Returns on equity is derived by dividing net profits by shareholders' equity. Only organisation 05 delivered consistent growth in equity return over the period. Two organisations (01 and 05) were able to achieve returns on equity superior to 30% during the years analysed. For the remainder of the organisations, the returns on equity were often between 5–10% and regularly below the ASX 200 benchmark's performance. Overall, there is considerable volatility from year to year in returns. However, the standard deviation of the results over the time period was 10.5% compared to the ASX 200 at 15.5%. This indicates that the returns of the sample companies are somewhat less volatile (or more predictable) than the benchmark.

The status of sustainability reporting is summarised in Table 5. The most commonly adopted standards were the Global Reporting Initiative and the Taskforce on Climate-Related Financial Disclosure, though it was notable that at least two of the organisations did not align to any of these standards. Most organisations report on scope one and two greenhouse gas emissions (negative) and resource recovery rates (positive) as a matter of

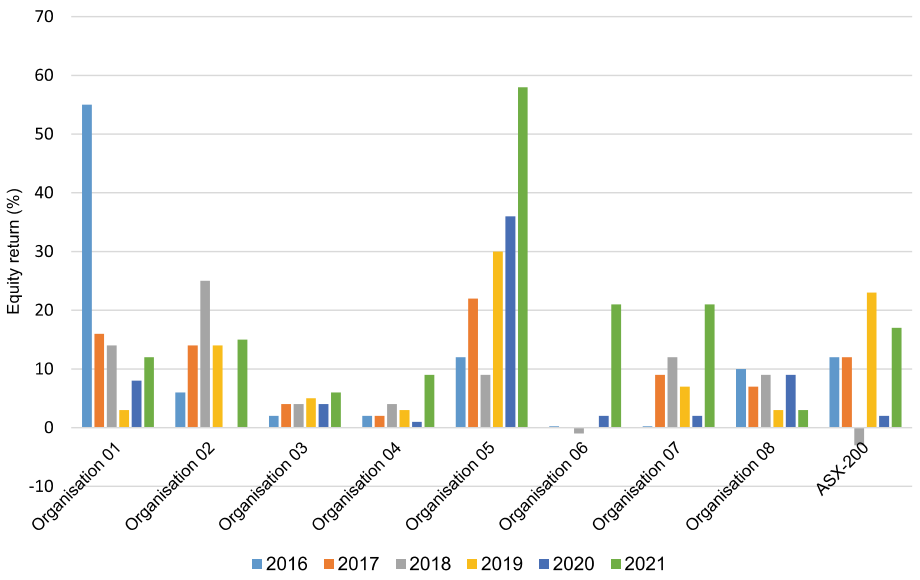


Fig. 3 Summary of the results against the return on equity indicator, 2016–2021

course, though it is notable that entities with emissions above 25,000 tonnes of carbon dioxide equivalent greenhouse gas are obliged to report those emissions annually anyway under the National Greenhouse and Energy Reporting (NGER) system. This requirement applied to at least five of the eight organisations analysed. While some organisations chose

Table 5 Summary of the results of the analysis of organisations' reporting and disclosure activities

Data item/organisation	01	02	03	04	05	06	07	08
Standards								
SASB-aligned	No	Yes	Yes	Yes	Yes	No	No	No
GRI-aligned	Yes	Yes	Yes	Yes	Yes	No	Yes	No
TCFD-aligned	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Externalities (negative)								
GHG scope one	Yes	Yes	Yes	Yes	Yes	No	Yes	No
GHG scope two	Yes	Yes	Yes	Yes	Yes	No	Yes	No
GHG scope three	Yes	No	No	No	No	No	No	No
Material consumption	No	Yes	No	Yes	No	No	Yes	No
Waste	No	Yes	No	No	Yes	No	Yes	No
Air pollution	No	Yes	No	Yes	Yes	No	No	No
Water use and pollution	No	No	No	No	Yes	No	Yes	No
Externalities (positive)								
Resource recovery rates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Contingencies								
Assets	No	No	No	No	No	No	No	No
Liabilities	No	No	Yes	No	Yes	Yes	No	Yes

to report targets to reduce emissions in the future, there were no examples where the organisations separated the emissions already priced from those not yet subject to a binding regulatory constraint. The contingent liabilities being reported related to land-related issues, such as ground contamination and leachate, rather than greenhouse gas emissions.

4.2 Results of the interviews

Below is a summary of the feedback provided through the interviews, organised according to the four units of observation in Sect. 3.1.2.

4.2.1 Responsive CSR

The interviewee representing ***Organisation 01*** shared details of how the firm was involved in recovery of recyclable materials from different waste streams. Demand from its clients is very much influenced by the existence of signals that come from other forms of regulation such as landfill charges.

The interviewee representing ***Organisation 02*** spoke about an initiative among clients, designers and specifiers in the construction industry, to increase demand for products that include higher levels of recycled content through specifications of materials based on environmental product declarations. These declarations allow clients to evaluate materials for their recycled content.

The interviewee representing ***Organisation 03*** believed there is a community expectation that construction materials will cause less environmental impact over time, though there are few standards or norms that warrant specific disclosure of performance.

4.2.2 Strategic CSR

The interviewee from ***Organisation 02*** felt that demand from clients asking for environmental product declarations was underdeveloped and may need some kind of regulation to mandate them. In this respect it has not yet become a strategic CSR matter, though may in the future.

On the matter raised by the interviewee from ***Organisation 03*** about community expectation, some competitors may innovate faster and capture an advantage in the market. This becomes an incentive to innovate, though there is a degree of uncertainty. The pace of change in consumer preferences is unknown, nor is the rate at which competitors may be able to deliver technological innovation.

The interviewee from ***Organisation 07*** discussed complexities associated with assigning values to environmental externalities. An internal carbon price had been considered to stimulate investment. Internal carbon prices are risky though, as inaccuracy may encourage misallocation of capital.

4.2.3 Innovation

In reference to the interviewee from ***Organisation 01***'s comments on responsive CSR in Sect. 4.2.1, the firm is effectively providing an outsourcing opportunity to other firms that may otherwise need to innovate on recycling but instead pay for a service to a third party.

Organisation 04 noted that making advancements in environmental performance often necessitates higher upfront costs, for which clients are not always willing to pay. The firm

therefore engages with financiers to identify ways to mobilise up front funding where possible, though access to capital is constrained and represents a barrier to innovation.

4.2.4 Connection to sustainability reporting activities

There was little direct connection between the practices and the sustainability information being disclosed in public reports, though two organisations did publish specific climate-related plans and targets. While not explicitly stated in the interviews, some of the participants worded themselves carefully. This is possibly due to the need to preserve trade secrets and confidential information and suggested some of the initiatives shared have the form of strategic CSR.

5 Summary

The interviews confirmed that all of the firms are involved in both responsive and strategic CSR, and they engage in innovation and are involved to varying degrees in sustainability disclosure. Table 6 confirms the main themes that emerged from the interviews, corresponding to the three main questions posed to each participant.

6 Discussion

The results of this study have indicated a number of characteristics about the relationship between the sustainability-related disclosures and the development of corporate innovation and performance by firms in the construction and demolition waste ecosystem.

Firstly, the longitudinal analysis revealed significant volatility in the financial performance of the firms examined. Only one firm demonstrated consistent growth in returns over the timeframe. This is different to the findings of Al Hawaj and Buallay (2022), who found manufacturing and construction—which are those into which most functional areas of the construction and demolition waste ecosystem would fit—to be among the sectors whose sustainability

Table 6 Summary of the themes emerging from the research

Discussion questions	Emerging themes
What is your main interest in C&D waste and why do you believe it is important?	All businesses are involved in C&D waste ecosystem either as a sole business activity or as part of a broader business
What do you consider to be the most important advantages and disadvantages of your organisation's approach to C&D waste management?	Several businesses made reference to approaches or activities that are not reported in sustainability disclosure documentation. A number also referred to the need to meet customer expectation in the future as a driver of these approaches, indicating the presence of strategic CSR
Are there any improvements that you would like to suggest, whether they be voluntary, regulatory or other?	While all businesses continue to be engaged the C&D waste ecosystem, several made reference to barriers. A recurring theme was the need to overcome those barriers, either through innovation or in some cases broader policy intervention

reporting practices were most likely to affect operational performance and financial results. In fact, these results would be more supportive of Unerman et al. (2018) and Zharfpeykan and Akroyd (2022), who found that the existence of sustainability indicators in a company's corporate disclosures did not translate into performance management systems within those firms. Unerman et al. (2018) claimed this can arise because the groups of people preparing sustainability impact information are different to those involved in senior management and/or the preparation of information contained in financial reports.

Secondly, firms in the Australian C&D waste ecosystem, particularly the larger ones including those listed on stock exchanges, are making a concerted effort to embrace many of the global trends towards voluntary sustainability reporting practice. This includes alignment with the Global Reporting Initiative, Sustainability Reporting Standards Board and the TCFD. There is a willingness to disclose negative externalities, which confirms the findings of Magrini et al. (2022) that found those externalities occurred across a range of areas including water, air quality and greenhouse gas emissions. However, some of the disclosure is not strictly voluntary. For example, some of the firms are required by law to report scope one and two greenhouse gas emissions as they meet specific thresholds under the National Greenhouse and Energy Reporting (NGER) regulations.

Thirdly, few of the activities and innovations shared by participants in the interviews are being reported in sustainability disclosures. Therefore, it is likely that firms are engaging in innovation and strategic CSR but consider that information commercially confidential, so it is not being reported publicly. Given that the readers of company disclosures for listed companies are investors and financiers, who are consumers of risk-based information such as TCFD disclosures, there is potential for CSR activity disclosed to be both responsive and strategic.

Equally, preparation of environmental product declarations is not being done for inclusion within sustainability reports, but rather as product-specific documentation that can lead to more sales to the extent they address the preferences of clients. In other words, it is both a response to client requests as well as an aide marketing and increasing sales. This suggests that the distinction between responsive and strategic CSR originally proposed by Porter and Kramer (2006) may not be quite so clearly delineated. While all businesses continue to be engaged the C&D waste ecosystem, several made reference to barriers. A recurring theme was the need to overcome those barriers, either through innovation or in some cases broader policy intervention.

Fourthly, some functional areas of the construction and demolition waste ecosystem, especially those involved with resource recovery and utilisation, are providing services to others on an outsourced basis. Some of the interviewees revealed that the innovations they are implementing are designed to service clients who are not, themselves, in a position to innovate. Although this is not directly contradictory to the Porter Hypothesis (Porter and van der Linde 1995), it does provide a basis for its qualification. That is, the presence of higher environmental standards may also lead to the creation of new business activities that occur outside incumbent firms who see advantages in purchasing services from third parties on an outsourced basis. In other words, where the innovation and competitiveness takes place depends upon the industrial organisation of the construction and demolition waste ecosystem and the industries it services.

7 Conclusion

This paper has revealed that, while external corporate communication provides an indication about the activities of firms, it does not necessarily provide all the detail of what firms in the Australian C&D waste ecosystem are doing to reduce environmental impacts. This can be explained in the context of some innovation being strategic in nature, where it is designed to induce a competitive advantage. Such innovations have the characteristics of trade secrets and are commercial in confidence. There is evidence to suggest that responsive CSR will at times have a strategic element, especially for those firms participating in the capital markets where stakeholders use that information to assess the risk profiles of firms. In these cases, the absence of information to make risk areas more visible may lead to impacts on the cost of capital of firms, which in turn may impact its operating cost structure and competitiveness. In other cases, such as greenhouse gas emissions, there can be a public interest in that information being made available. In these cases, mandating disclosure through regulation can likely be justified. Customers, societal stakeholders, financiers, investors and governments can have a reasonable degree of confidence in external communication on sustainability matters by firms, though it is important that these stakeholders acknowledge such reporting has its limits. Much of the innovation taking place is strategic and designed to give firms a competitive advantage. It is natural information of this nature would be commercial in confidence and contain trade secrets and would therefore have boundaries placed around its external distribution.

There are opportunities resulting from this paper to reform both practice and theory. In practice, proponents of disclosure frameworks should acknowledge, in explicit terms, that firms have the right not to disclose CSR or operational sustainability information that is commercial in confidence and strategic in its nature. This would help to make the limitations of disclosures clearer and modify the expectations of those consumers of the external communications such as investors, financial services providers, stakeholders and regulators. It is equally important, notwithstanding, to re-emphasise the impact that this kind strategic CSR can have on innovation by firms, especially in the emerging resource recovery areas of practice. This would lead to less risk of greenwashing in corporate communications. It is also important that theories of innovation be modified to take greater account of the proactive but often-times confidential efforts firms make to capture market opportunities.

Moving beyond theoretical understandings that tighter environmental standards or existential business threats are among the most effective motivators for *reactive* innovation, this paper illustrates the opportunity to gain competitive advantage, *strategic* in its nature, is equally influential.

The paper therefore provides a new and interesting insight into the behaviour of firms. Whereas previously, concerns over greenwashing suggest that firms exaggerate sustainability performance, this paper reports evidence that much innovation remains confidential. If, as the Port Hypothesis would suggest, firms are innovating in response to higher environmental standards, there is a natural incentive to delay external communication until new products can be sold in the marketplace. There are implications for policymakers considering if and how to regulate sustainability disclosure, and for managers seeking to improve sustainability communication with stakeholders. In particular, the implication for managers is to be more specific about the difference between strategic and responsive CSR with stakeholders, which would help not only for stakeholders to better digest external communications, but would also minimise reputational risks associated with greenwashing.

7.1 Limitations

This study is limited by its empirical focus on the C&D waste sector in Australia. Even though this is an important area for reducing externalities across society—and indeed some of the firms are also operating in international markets—the sample is relatively small. Notwithstanding, there is an opportunity for further research to be carried out within other sectors and within other countries to validate the global applicability.

Funding This paper was prepared during doctoral candidature with funding provided through The University of Adelaide, through a Faculty of Science, Engineering and Technology divisional scholarship. The funding provider played no role in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Data availability Much of the dataset analysed during the current study is not publicly available as it was collected by the author from human participants in accordance with the conditions of approval provided by the Human Research Ethics Committee (HREC) of The University of Adelaide (approval H-2021-069) and is protected due to confidentiality and privacy undertakings. The corresponding author will act on reasonable requests to release some of the restricted data.

Declarations

Conflict of interest The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Al Hawaj, A. Y., & Buallay, A. M. (2022). A worldwide sectorial analysis of sustainability reporting and its impact on firm performance. *Journal of Sustainable Finance & Investment, 12*(1), 62–86. https://doi.org/10.1080/20430795.2021.1903792

Aldieri, L., Brahmi, M., Bruno, B., & Vinci, C. P. (2021a). Circular economy business models: The complementarities with sharing economy and eco-innovations investments. *Sustainability (basel, Switzerland), 13*(22), 12438. https://doi.org/10.3390/su132212438

Aldieri, L., Brahmi, M., Chen, X., & Vinci, C. P. (2021b). Knowledge spillovers and technical efficiency for cleaner production: An economic analysis from agriculture innovation. *Journal of Cleaner Production, 320*, 128830. https://doi.org/10.1016/j.jclepro.2021.128830

Austin, A., & Rahman, I. U. (2022). A triple helix of market failures: Financing the 3Rs of the circular economy in European SMEs. *Journal of Cleaner Production, 361*, 132284. https://doi.org/10.1016/j.jclepro.2022.132284

Benachio, G. L. F., Freitas, Md. C. D., & Tavares, S. F. (2020). Circular economy in the construction industry: A systematic literature review. *Journal of Cleaner Production., 260*, 121046. https://doi.org/10.1016/j.jclepro.2020.121046

Bernard, H. R. (2018). *Research methods in anthropology: Qualitative and quantitative approaches* (6th ed.). Lanham, MD: Rowman & Littlefield.

Chen, Y.-C., Hung, M., & Wang, Y. (2018). The effect of mandatory CSR disclosure on firm profitability and social externalities: Evidence from China. *Journal of Accounting & Economics, 65*(1), 169–190. https://doi.org/10.1016/j.jacceco.2017.11.009

Chioatto, E., & Sospiro, P. (2023). Transition from waste management to circular economy: The European Union roadmap. *Environment, Development and Sustainability, 25*(1), 249–276. https://doi.org/10.1007/s10668-021-02050-3

Coase, R. H. (1960). The problem of social cost. *The Journal of Law and Economics, 56*(4), 837–877.

Coase, R. H. (1988). *The firm, the market and the law*. Chicago: The University of Chicago Press.

Coen, D., Herman, K., & Pegram, T. (2022). Are corporate climate efforts genuine? An empirical analysis of the climate 'talk–walk' hypothesis. *Business Strategy and the Environment, 31*(7), 3040–3059. https://doi.org/10.1002/bse.3063

Clean Energy Finance Corporation, & Arup. (2021). *Energising resource recovery: The Australian opportunity*. Retrieved from Sydney, Australia:

de Silva Lokuwaduge, C. S., & de Silva, K. M. (2022). ESG Risk Disclosure and the Risk of Green Washing. *Australasian Accounting, Business & Finance Journal, 16*(1), 146–159. https://doi.org/10.14453/aabfj.v16i1.10

Delgado-Ceballos, J., Ortiz-De-Mandojana, N., Antolín-López, R., & Montiel, I. (2023). Connecting the Sustainable Development Goals to firm-level sustainability and ESG factors: The need for double materiality. *Business Research Quarterly, 26*(1), 2–10. https://doi.org/10.1177/23409444221140919

Di Foggia, G., & Beccarello, M. (2022). Introducing a system operator in the waste management industry by adapting lessons from the energy sector. *Frontiers in Sustainability (lausanne)*. https://doi.org/10.3389/frsus.2022.984721

Fatima, T., & Elbanna, S. (2022). Corporate Social Responsibility (CSR) implementation: A review and a research agenda towards an integrative framework. *Journal of Business Ethics, 10*, 1–17. https://doi.org/10.1007/s10551-022-05047-8

Financial Conduct Authority. (2022). FCA proposes new rules to tackle greenwashing [Press release]. Retrieved from https://www.fca.org.uk/news/press-releases/fca-proposes-new-rules-tackle-greenwashing

Friedman, M. (1970). A Friedman doctrine—The Social Responsibility Of Business Is to Increase Its Profits. *The New York Times*. Retrieved from https://www.nytimes.com/1970/09/13/archives/a-friedman-doctrine-the-social-responsibility-of-business-is-to.html

Hamrouni, B., Bourouis, A., Korichi, A., & Brahmi, M. (2021). Explainable ontology-based intelligent decision support system for business model design and sustainability. *Sustainability (basel, Switzerland), 13*(17), 9819. https://doi.org/10.3390/su13179819

Helbling, T. (2020). Externalities: Prices do not capture all costs. *IMF Back to Basics Finance & Development Series*. Washington DC. https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/Externalities

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2013). Environment: Waste production must peak this century. *Nature, 502*(7473), 615. https://doi.org/10.1038/502615a

Horn, H., Wieman, V., & Ohl, A. (2022). *Navigating the ESG landscape: Comparison of the "Big Three" disclosure proposals*. Retrieved from https://corpgov.law.harvard.edu/2022/10/10/navigating-the-esg-landscape-comparison-of-the-big-three-disclosure-proposals/

Iodice, S., Garbarino, E., Cerreta, M., & Tonini, D. (2021). Sustainability assessment of construction and demolition waste management applied to an Italian case. *Waste Management (elmsford), 128*, 83–98. https://doi.org/10.1016/j.wasman.2021.04.031

Jørgensen, S., Mjøs, A., & Pedersen, L. J. T. (2022). Sustainability reporting and approaches to materiality: Tensions and potential resolutions. *Sustainability Accounting, Management and Policy Journal Print, 13*(2), 341–361. https://doi.org/10.1108/SAMPJ-01-2021-0009

Kabirifar, K., Mojtahedi, M., & Wang, C. C. (2021). A systematic review of construction and demolition waste management in Australia: Current practices and challenges. *Recycling (basel), 6*(2), 34. https://doi.org/10.3390/recycling6020034

Laffont, J.-J. (2008). *Externalities: Definition in the New Palgrave dictionary of economics*. London: Palgrave Macmillan.

Latapí Agudelo, M. A., Jóhannsdóttir, L., & Davídsdóttir, B. (2019). A literature review of the history and evolution of corporate social responsibility. *International Journal of Corporate Social Responsibility, 4*(1), 1–23. https://doi.org/10.1186/s40991-018-0039-y

Lemley, M. A. (2008). The surprising virtues of treating trade secrets as IP rights. *Stanford Law Review, 61*(2), 311–353.

Lykkesfeldt, P., & Kjaergaard, L. L. (2022). *Taking already implemented non-financial reports a step further*. New York: Springer.

Magrini, C., Dal Pozzo, A., & Bonoli, A. (2022). Assessing the externalities of a waste management system via life cycle costing: The case study of the Emilia-Romagna Region (Italy). *Waste Management (ELMSFORD), 138*, 285–297. https://doi.org/10.1016/j.wasman.2021.12.009

Mathews, T. (2019). *A history of Australian equities* (ISSN 1448-5109 (online)). Retrieved from Sydney: https://www.rba.gov.au/publications/rdp/2019/pdf/rdp2019-04.pdf

Mazzucato, M., & Ryan-Collins, J. (2022). Putting value creation back into "public value": From market-fixing to market-shaping. *Journal of Economic Policy Reform, 25*(4), 345–360. https://doi.org/10.1080/17487870.2022.2053537

Mirdar Harijani, A., & Mansour, S. (2022). Municipal solid waste recycling network with sustainability and supply uncertainty considerations. *Sustainable Cities and Society, 81*, 103857. https://doi.org/10.1016/j.scs.2022.103857

O'Dwyer, B., & Unerman, J. (2020). Shifting the focus of sustainability accounting from impacts to risks and dependencies: Researching the transformative potential of TCFD reporting. *Accounting, Auditing & Accountability Journal, 33*(5), 1113–1141. https://doi.org/10.1108/AAAJ-02-2020-4445
Parker, S. C. (2012). Theories of entrepreneurship, innovation and the business cycle. *Journal of Economic Surveys, 26*(3), 377–394. https://doi.org/10.1111/j.1467-6419.2012.00728.x
Pickin, J., Wardle, C., O'Farrell, K., Nyunt, P., & Donovan, S. (2020). *National Waste Report 2020*. Retrieved from Canberra.
Pizzi, S., Principale, S., & De Nuccio, E. (2022). Material sustainability information and reporting standards. Exploring the differences between GRI and SASB. *Medari Accountancy Research*. https://doi.org/10.1108/MEDAR-11-2021-1486
Porter, M. E. (1990). *The competitive advantage of nations*. London: Free Press.
Porter, M. E., & Kramer, M. R. (2006). Strategy and society: The link between competitive advantage and corporate social responsibility. *Harvard Business Review, 84*(12), 78–163.
Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *The Journal of Economic Perspectives, 9*(4), 97–118. https://doi.org/10.1257/jep.9.4.97
Proposal for a Directive of the European Parliament and of the Council on substantiation and communication of explicit environmental claims (Green Claims Directive), COM/2023/166 final C.F.R. (2023).
Robins, F. (2005). The Future of Corporate Social Responsibility. *Asian Business & Management, 4*(2), 95–115. https://doi.org/10.1057/palgrave.abm.9200125
Saldaña, J. (2021). *The coding manual for qualitative researchers* (4E ed.). SAGE: New York.
Schumpeter, J. A. (1939). *Business cycles; a theoretical, historical, and statistical analysis of the capitalist process* (1st ed.). New York: McGraw-Hill Book Company Inc.
Shaikh, E., Brahmi, M., Thang, P. C., Watto, W. A., Trang, T. T. N., & Loan, N. T. (2022). Should I Stay or Should I Go? Explaining the Turnover Intentions with Corporate Social Responsibility (CSR), Organizational Identification and Organizational Commitment. *Sustainability (basel, Switzerland), 14*(10), 6030. https://doi.org/10.3390/su14106030
Shooshtarian, S., Maqsood, T., Wong, P., & Yang, R. (2020). Australian construction and demolition waste management system in Australia: Investigation of challenges and opportunities (preprints). https://doi.org/10.20944/preprints202007.0118.v1
Soh Young, I., & Schumacher, K. (2021). Carbonwashing: ESG data greenwashing in a post-Paris World. In: Settling climate accounts: Navigating the road to net zero. Palgrave Macmillan: Cham
Tao, H., Zhuang, S., Xue, R., Cao, W., Tian, J., & Shan, Y. (2022). Environmental finance: An interdisciplinary review. *Technological Forecasting & Social Change, 179*, 121639. https://doi.org/10.1016/j.techfore.2022.121639
Thomson, J. (2021). *Waste Remediation and Materials Recovery Services in Australia*. Retrieved from Melbourne.
Unerman, J., Bebbington, J., & O'Dwyer, B. (2018). Corporate reporting and accounting for externalities. *Accounting and Business Research, 48*(5), 497–522. https://doi.org/10.1080/00014788.2018.1470155
United Nations Environment Programme. (2015). *Global Waste Management Outlook* (ISBN 978-92-807-3479-9). Retrieved from Nairobi: https://www.unenvironment.org/resources/report/global-waste-management-outlook
Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). SAGE: New York.
Zharfpeykan, R., & Akroyd, C. (2022). Factors influencing the integration of sustainability indicators into a company's performance management system. *Journal of Cleaner Production, 331*, 129988. https://doi.org/10.1016/j.jclepro.2021.129988

Chapter 8. Publication four and statement of authorship

This section presents the publication entitled: *The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia*.

8.1 Statement of authorship

The statement of authorship is provided below in Table 11.

Table 11 – Statement of authorship for publication four

Title of paper:	**The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia.**			
Publication status:	Published	×	Accepted for publication	
	Submitted for publication		Unpublished and unsubmitted work written in manuscript style	
Publication details:	Rossetto, D. (2023). "The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia." Carbon Neutrality Volume 2 (Issue 2). DOI: https://doi.org/10.1007/s43979-023-00063-7 Reproduced in accordance with the publishing agreement.			
Name of principal author:	Daniel Marc Rossetto			
Contribution to the paper:	Research design, research execution and sole author			
Overall percentage:	100%			
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.			
Signature:				
Date:	14/03/2024			

8.2 Specific aims of the paper

The specific aim of this paper was to assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management. The paper addresses the research project's fifth objective, as articulated in the introduction, to: *Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management*.

The paper presents new and original research analysing the relative importance of carbon markets to the waste management sector's contribution to climate change commitments under the Paris Agreement. It comes as international efforts intensify on defining modalities for participation in the new mechanism under Article 6.4 of the Paris Agreement, reforms to developing countries' access to climate finance gathers momentum through approaches like the Bridgetown Initiative 2.0; and as individual countries seek to optimise domestic carbon market mechanisms, so they are fit-for-purpose to support Nationally Determined Contributions (NDC).

The research described in the paper deployed longitudinal and financial analysis - in the context of the Australian domestic carbon market - to explore how important revenue generation mechanisms are relative to other incentives and project revenues in improved waste management. It identified that almost 90% of credits issued to date have been generated by landfill to electricity projects. More ambition will be needed to realise the potential of circular solutions that reduce, recover and utilise waste before disposal.

While there is scrutiny being applied to the environmental integrity of carbon markets, the article illustrated the significant contribution carbon revenues can make to project additionality at the investment-decision stage, adding between 2-10% to ex-ante estimates of pre-tax equity returns. It therefore added depth to understanding of circumstances in which simultaneous use of revenue support mechanisms, cost of capital support programs and landfill levies in the deployment of waste management projects is justified. The findings of this paper will impact approaches to carbon market and climate finance reforms aforementioned, as well as how countries develop domestic energy and waste policies to interact with international mechanisms.

8.3 Current citations

This paper was published in September 2023, so there are not yet any citations.

8.4 Publication four

The paper as published in September 2023 is now included.

Rossetto *Carbon Neutrality* (2023) 2:25
https://doi.org/10.1007/s43979-023-00063-7

ORIGINAL ARTICLE Open Access

The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: insights from Australia

Daniel Rossetto[1*]

Abstract

This paper presents research that analyses the relative importance of carbon markets to sustainable waste management projects in Australia. It identifies that a large proportion of carbon credits issued have been generated by landfill to electricity projects, which effectively rely on the continuation of landfilling practices. More ambition is needed to realise the potential of circular solutions that reduce, recover and utilise waste before disposal.

The research also shows that, through modelling the financial performance of two theoretical waste to energy projects that would result in diversion of waste from landfill, simultaneous use of revenue support mechanisms (carbon markets and renewable energy certificate programs), cost of capital support programs (like concessional finance) and avoided landfilling levies in the deployment of waste management projects can be justified. The paper illustrates the significant contribution carbon revenues can make to project additionality at the investment-decision stage, adding between 2–10% to *ex-ante* estimates of pre-tax equity returns. This shows that a project's additionality is not invalidated in cases where it accesses more than one support mechanism.

There are many policy and practice applications for these findings in Australia and globally. They include within ongoing international efforts to define modalities for the new *Article 6.4 mechanism* under the Paris Agreement, reforms to how developing countries access to climate finance (including, but not limited to, the Bridgetown Initiative 2.0 (The Bridgetown Initiative 2.0: https://www.un.org/sustainabledevelopment/blog/2023/04/press-release-with-clock-ticking-for-the-sdgs-un-chief-and-barbados-prime-minister-call-for-urgent-action-to-transform-broken-global-financial-system/)); and through the domestic policies and mechanisms countries adopt so they are fit-for-purpose to support implementation of Nationally Determined Contributions (NDC).

Highlights

- Almost 90% of carbon credits from projects in Australian waste sector use landfill gas.
- Carbon revenues can lift pre-tax ex ante equity returns for waste projects by 2–10%.

*Correspondence:
Daniel Rossetto
daniel.rossetto@adelaide.edu.au
Full list of author information is available at the end of the article

- Scaled-up use of markets can lead to higher penetration of circular resource recovery.
- Additionality can exist notwithstanding simultaneous use of incentive mechanisms.
- Multiple revenue streams can provide hedge in volatile energy and carbon markets.

Keywords Carbon markets, Climate investment, Finance, Additionality, Paris Agreement and market-based mechanisms

1 Introduction

How to manage waste effectively is a global challenge. The United Nations Environment Programme [80] and Wu et al. [84] estimated that as many as 10 billion tonnes of waste is being generated globally every year, with over 40% being disposed into landfill. Disposal practices were analysed by Papastamoulis et al. [54] and Magrini et al. [41], who noted that sending waste to landfill produces negative externalities such as air and water pollution, particulate emissions and leachate, odours and health and safety hazards like fire. Bian et al. [8], Struthers et al. [76] and Yang et al. [86] also noted that disposal can generate greenhouse gas emissions and contribute to human-induced climate change. Disposal of organic waste leads to anaerobic decomposition and generates methane gas, recognised as a potent greenhouse gas [79]. Accordingly, countries have prioritised utilisation of methane or waste avoidance strategies within national climate change mitigation plans under the Paris Agreement [25, 28].

Scholars have sought to focus on how to incentivise improvements in the sustainability of waste management practice on an economic or financial basis. While laws and regulations that either prohibit a certain practice or mandate another can be common, three general approaches or mechanisms have been identified to provide economic and financial incentives.

The first is where the positive social and environmental externalities associated with improved waste management practice are rewarded with new income. These can be described as *revenue support mechanisms*. Plöchl et al. [56] and Lo and Cong [38] identified systems that allow waste project proponents to increase the revenues based on monetisation of positive externalities they create by linking those impacts to the creation of renewable energy certificates or carbon credits.

The second grouping of instruments are *cost of capital support mechanisms*. Rossetto [63], Kapoor and Medha [33], Calvet et al. [11] and Rasheed et al. [61] broadly categorised these instruments as climate finance. This is because such instruments lead to a reduction in the cost of financing for projects that deliver positive environmental or climate-related externalities. Examples of the instruments include grants that subsidise capital cost, interest rate subsidies, investment guarantees, liquidity for financing that is not otherwise available in the market either by the tenor or volume of the financial commitment, or subordinated equity investment schemes – in which one investor, such as a climate finance fund, agrees to wait until another investor has been paid before it is compensated.

The final set of mechanisms can be described as *negative externality levies*. Mazzanti et al. [46] and Matheson [45] noted that various fiscal incentives from landfill charges to consumption taxes are commonly applied to waste management practices. These charges act as an incentive to find an alternative to the prevailing waste management practice.

The availability of choice in mechanisms prompts an important question, which is the focus of this paper: How important are revenue generation mechanisms relative to the others to incentivise improvements in sustainable waste management? This question shall be explored looking at applications in Australia, which provides an interesting context as it has and continues to deploy variations of all three mechanisms – revenue support, cost of capital support and negative externality levies - to encourage better waste management practice. There have been notable criticisms and rebuttals about the additionality – a term that will be explained further in Section 3.3 – of waste to energy projects in Australia [22, 40]. The issues that have arisen in Australia – such as the multiple sources of revenue and questions about additionality in this context – are relevant to most countries. This is of particular importance given countries are seeking to design a new project-based mechanism under Article 6.4 of the Paris Agreement on climate change have emphasised the need to reform understanding and assessment of additionality [48, 68]. Very little work has been done to analyse the impact of parallel participation in one or more forms of the support mechanisms on project additionality, be that in Australia or globally.

1.1 Research framework and chapter structure

This paper presents new and original research analysing the relative importance of carbon markets to the abatement of emissions in the waste management sector. It is

structured to describe the support mechanisms available (Section 2) and then present the findings of a literature review that examined waste management and climate policy, market-based incentive mechanism applications in the context of international mechanisms under the United Nations Framework Convention on Climate Change (UNFCCC), the concept of additionality and then national level application with the example of Australia (Section 3). It then provides details of the empirical research undertaken (Section 4) and the results (Section 5), followed by the discussion and conclusion (Sections 6 and 7).

2 Theoretical description of the mechanisms

According to the Concise Oxford Dictionary of Current English [23], an incentive is "*a thing that motivates or encourages someone to do something*" (Page 176). This definition can be extended to methods that promote more sustainable waste management practice. As suggested in the introduction (Section 1), there are three main ways to motivate or encourage voluntary changes in practice in ways that go beyond regulatory actions to remove choice for private actors either by prohibiting certain activities or mandating others. These incentives are revenue support mechanisms, cost of capital support mechanisms and negative externality levies, which are elaborated in Sections 2.1, 2.2 and 2.3 respectively.

2.1 Revenue support mechanisms

Revenue support mechanisms allow project proponents to monetise positive impact, which can in turn boost returns above investment hurdle rates [38, 56]. Such incentives often take the form of certificates or property rights issued to projects in exchange for a positive externality, which can, in turn, be sold to firms that seek to reduce their own liabilities for negative externality generation. This allows a form of market-based negotiation to take place between parties as is described within Coase's theory [18, 20, 30]. The result is a new revenue stream for qualifying activities and projects.

In order to qualify for such mechanisms, projects generally need to prove they are additional to business as usual. The implication of a project not being additional is that it is *business-as-usual*, so its performance is the same as the baseline and its impact, by definition, is zero. Scholars have found varying levels of success of revenue support mechanisms in supporting improvements in waste management practice. Agamuthu et al. [1] found that economic incentives were among four main drivers of improved practice in Asia, along with human, institutional and environmental factors. Rasheed et al. [61] made a similar conclusion, though called for scaling-up of incentives. Asare et al. [4] found evidence that these programs work more effectively than levies and charges. Peng et al. [55] highlighted the potential for market-based systems to be expanded beyond greenhouse gas emissions and to the recovered materials themselves.

2.2 Cost of capital support mechanisms

Cost of capital is an important expense for businesses and is used in investment decision-making. Businesses use the weighted average cost of capital (WACC) as a metric that looks at the relative costs of its equity and debt financing - and the ratio at which both are used – though often defer to return on equity as the basis for investment decisions [24, 74]. Economic incentives can be offered to improvements in waste management practice in the form of cost of capital support mechanisms. O'Dwyer and Unerman [53], Calvet et al. [11] and Caldecott [10] noted the impact at the macro-level on cost of capital arising from central bank practices that allocate more risk to polluting activities. These kinds of macro-level activities can have a corresponding impact on capital allocation and investment decision-making.

At the project level, scholars such as Tao et al. [78] and Amighini et al. [3] identified the broader movements in green and climate-themed finance. A number of instruments were identified that can be used to provide financial incentives for waste management projects. These include grants that subsidise the capital cost, interest rate subsidies, investment guarantees, liquidity for financing that is not otherwise available in the market either by the tenor or volume of the financial commitment, or subordinated equity investment schemes. While cost of capital support mechanisms are similar to revenue support, the positive externalities are less likely to result in creation of a property right [63].

2.3 Negative externality levies

As set out in the introduction, other instruments broadly termed negative externality levies can provide incentives for improved waste management practice and resource recovery. These arise because polluting activities attract a charge, which can be sufficient for actors to look for least costly alternatives. From a theoretical perspective, this aligns such mechanisms with the Porter's Hypothesis, which states that higher environmental standards drive innovation and enhanced competitiveness [57, 58].

Jiménez-Rivero and García-Navarro [32], Shooshtarian et al. [72] and Matheson [45] are among a number of scholars that have validated landfill charges – as an example of this kind of instrument - as a driver of resource recovery. Wu et al. [83] found that there is a tendency for waste disposal activities to seek out the

lowest cost alternative, where there are differences in charges between jurisdictions, implying that higher landfill charges do not necessarily guarantee more resource recovery.

3 Literature review

This section contains details of a literature review. Its four sub-sections are broken up into waste management and climate policy, market-based incentive applications in the context of international mechanisms under the UNFCCC, the concept of additionality and then project-based mechanisms in the context of Australia. These sub-sections were selected to provide an overview of previous writings and practice background of essential need to addressing the research questions. Relevant literature was identified on recognised academic search platforms such as Google Scholar and Mendeley, as well as other relevant practice literature, using key words such as *incentives*, *carbon markets*, *climate finance*, *waste management*, *additionality* and *market-based mechanisms*.

3.1 Waste management and climate policy

There is an emerging understanding about the link between waste to landfill and its contribution to greenhouse gas emissions. Recent literature indicates several relevant areas.

The *first area* is the extent to which landfilling contributes to climate externalities. Nisbet et al. [51] found that atmospheric methane emissions, which arise from landfills that are not capped, were a substantial problem. Magrini et al. [41] looked at landfilling practices in the Italian region of Emilia-Romagna and found the largest climate externalities were connected to emissions from transport, though resource recovery can compensate. Liang et al. [36] used life-cycle assessment used to analyse environmental impacts of steelmaking techniques including the use of scrap steel, concluding that savings in greenhouse gas emissions were the major benefit associated with resource recovery. Rossetto [65] showed that steelmaking using recycled scrap steel can reduce greenhouse gas emissions and incentives may arise from removal of free allocation policies in the EU's emissions trading system.

The *second area* is where problems should be solved. Are they a matter for sub-national entities or countries, or do they require international cooperation? Kellenberg [34] analysed trade data that indicated a high degree of waste trade between counties, especially those in regional proximity. Martínez et al. [44] tracked over 100 categories of waste over the 2001-19 revealed traded waste moves mainly from developed to developing countries.

Rossi and Morone [66] noted a recent tendency for some countries to prohibit international trade in waste trade, both imports and exports, which can cause unintended consequences. Along these lines and as an example, the Council of Australian Governments [19] outlined the national plan to limit or prohibit exports of plastics, paper, tyre and glass waste. The literature suggests that regional waste ecosystems exist, though some governments can and do intervene, limiting imports and exports of waste.

The *third and final area* is what the barriers are to better practice and, by extension, what are the most effective solutions are to encourage reductions in landfilling. Papastamoulis et al. [54] carried out a literature review-based study to identify the recoverable value in waste sent to landfill to move away from the zero-value mentality. Allwood [2] had previously promoted a waste hierarchy that recognises the recoverable value in waste materials, in an attempt to move away from the zero-value mindset. Mahpour [42] identified that there were many barriers to resource recovery and they needed to be prioritised. Mhatre et al. [47] found that meeting or complying with environmental standards is, itself, a barrier to resource recovery. Xie et al. [85] noted the most efficient solution would come from maximising the emission reduction potential of landfill avoidance.

Benachio et al. [7] recognised that cost effectiveness of investments is an important barrier limiting further resource recovery in construction and demolition waste. Su et al. [77] undertook research to design policy mechanisms and simulate efficiency, which concluded subsidy policies were inferior to market-based approaches. Maqsood et al. [43] carried out a review of waste end-use markets in Australia indicated they are underdeveloped and recommended removal of information barriers.

Söderholm and Ekvall [73] carried out a review-based study looking at impacts of tradable recycling credits, virgin material taxes and recycling subsidies. Shah et al. [70] recommended using waste as a fuel source for power generation based on a study in India. Purchase et al. [60] called for a global framework including incentive mechanisms and further trade, contrasting with the kind of waste trade prohibition policies. Schwarz et al. [69] carried out life cycle assessment to show that valuing greenhouse gas emission reduction potential is the best way to reduce plastic waste to landfill. Ginga et al. [27] carried out a study in China suggesting that adopting circular business models will lead to less waste going to landfill.

Shooshtarian et al. [71] suggested policy responses including subsidies and taxes. Asare et al. [4] examined waste management practice in Ghana revealed that incentives are needed to motivate private actors. Peng et al. [55] sought to ask why a cap-and-trade program

cannot be designed for waste trading like those used for greenhouse gas emissions. Hua et al. [31] found that incentive policies will provide a clearer driver for waste recovery than subsidies based on investigations in China.

3.2 Market mechanisms in the context of international climate change cooperation

The following section recounts literature on international climate change cooperation under the UNFCCC, deployment of market-based mechanisms and issues associated with transition from the Kyoto Protocol architecture to the Paris Agreement. It also covers the development of the so-called Nationally Determined Contributions (NDC) under the Paris Agreement, the extent to which emissions from landfilling of waste represent a focus within these plans and the intention among countries to use market mechanisms to achieve these goals.

On the deployment of market mechanisms, significant experience has been gained through the Clean Development Mechanism (CDM) a project-based mechanism under the UNFCCC's Kyoto Protocol. The CDM's twin purpose was to assist developing countries achieve sustainable development and countries with targets under the Kyoto Protocol to achieve them at lowest cost. The mechanism has seen over 8,000 projects and programs registered worldwide, leading to reduction just above 2.4 billion emission reductions since its inception in 2005 [81]. Credits issued under the CDM could be sold to companies needing to comply with compliance requirements under the various emissions trading programs, as well as by countries seeking to meet targets under the first and second commitment periods of the Kyoto Protocol. The revenue transformed marginal projects, which were not otherwise viable, into profitable investments.

Several scholars have considered the effectiveness of the CDM. Lo and Cong [38] conducted analysis of over 3,000 CDM projects and found that four countries - China, South Korea, Brazil and India – dominated the supply side of the market. Butu et al. [9] acknowledged the CDM's major criticism is that it failed to achieve even geographical distribution, particularly in the least developed countries, though it did succeed in delivering sustainable development benefits. Rossetto [64] found that the CDM's failure to achieve a more balanced geographical distribution was partly connected to the decay in demand for its credits caused by the transition from the Kyoto Protocol to the Paris Agreement.

The transition from the 1997 Kyoto Protocol (*Kyoto*) to Paris Agreement (*Paris*) was triggered by an understanding among countries that the Kyoto represented an imperfect approach to tackling climate change at the international level. Kuyper et al. [35] undertook a stocktake of UNFCCC climate negotiations and found one of the major limitations of Kyoto was that it featured emission reduction targets only for developed countries. The study noted that concerns had also arisen over environmental integrity of CDM projects, with some believing it had allowed some projects to be registered and produce credits that were not truly additional to business-as-usual practice. In other words, the *additionality* – a concept that will be explored in more detail in Section 3.3 of – was brought into question. Michaelowa et al. [49] noted that environmental integrity concerns associated with additionality were an important factor behind the definition of a new project-based incentive mechanism – known as the *Article 6.4 mechanism* (of the Paris Agreement) to eventually replace the CDM. Another feature of the Paris Agreement is that each country now has its own emission reduction targets, known as its Nationally Determined Contribution (NDC).

Reductions in emissions from waste are a common measure under the Paris Agreement within NDCs. Powell et al. [59] noted countries representing up to 85% of emissions from global waste generation plan to reduce greenhouse gases from the sector.

Table 1 provides an overview of the NDCs put forward by a selection of countries in Asia and the Pacific. It shows each country's 2030 emission reduction target, its base year emissions and the relative contribution that the waste sector makes to its overall emissions. All data in the table was taken from the documents prepared by each country and published on the NDC registry (https://unfccc.int/NDCREG). The column farthest to the right of the table illustrates whether those countries intend to use the market-based (*revenue support*) mechanisms of the Paris Agreement (such as the Article 6.4 mechanism) to assist in achievement of either the conditional or unconditional components of the NDC. Only Malaysia explicitly excluded the use of markets and Australia has not yet decided.

Countries included in Table 1 can be viewed as part of a regional ecosystem in which waste is imported and exported. Waste generated in one nation within the region may find its way into the emissions inventory of another. As previously covered in Section 3.1, Australia is now taking action to limit exports of plastic, rubber tyre, glass and paper waste, creating some friction within this ecosystem. It was selected as the focus of this study because export constraints will lead to increasing domestic waste management requirements, the unintended consequence of which may be increased risk of landfilling.

3.3 Exploring additionality

As can be seen from the previous section, much of the criticism of the CDM originated from concerns about the

Table 1 Summary of nationally determined contributions of selected countries in Asia & the Pacific and contribution of waste

Country	2030 Target	Base year	Base year emissions			Intention to use markets
			Total (tCO_2e)	Waste (tCO_2e)	Waste (%)	
Australia	43% reduction in total absolute emissions by 2030	2005	608,650,000	14,280,000	2.35%	Maybe
China	60–65% reduction in emissions intensity per unit GDP by 2030	2005	7,250,000,000	127,000,000	1.75%	Yes
India	45% reduction in emissions intensity per unit GDP by 2030	2005	1,820,000,000	67,800,000	3.73%	Yes
Indonesia	29% (unconditional) and 41% (conditional) reduction on business as usual	2005	628,000,000	93,800,000	14.94%	Yes
Japan	46% reduction in total absolute emissions by 2030	2013	1,340,000,000	22,530,000	1.68%	Yes
Malaysia	45% reduction in 2005 absolute emissions by 2030.	2005	252,000,000	21,900,000	8.69%	No
New Zealand	50% reduction in 2005 absolute emissions by 2030.	2005	57,240,000	4,380,000	7.65%	Yes
Philippines	Peak in absolute emissions by 2030. 75% reduction, 2.5% of which is unconditional.	2005	159,000,000	16,400,000	10.31%	Yes
Singapore	Reach an absolute target of 60mt of emissions by 2030.	2005	36,300,000	338,000	0.93%	Yes
South Korea	40% reduction on absolute emissions by 2030 from 2018 base year.	2018	739,000,000	19,200,000	2.60%	Yes
Thailand	Unconditional 30% reduction against business as usual and conditional 40%.	2005	350,000,000	19,400,000	5.54%	Yes
Vietnam	Unconditional 16% reduction on business as usual and unconditional 44%.	2005	217,000,000	12,400,000	5.71%	Yes

Source: NDC Registry (https://unfccc.int/NDCREG accessed on 13 June 2023)

additionality of project activity. Additionality is relevant not just to the CDM but is also an important concept in determining which activities are eligible for financial incentive programs. Luukkonen [39], for example, indicated that additionality has been used in assessment of eligibility for grant programs in the European Union that have sought to incentivise research and development by private sector entities. Carter et al. [13] also found it was relevant to allocating capital under Official Development Assistance (ODA) programs. The authors found, however, that it was often a subjective process and that systemic biases among development finance institutions that lead to projects receiving ODA funding, rather than objective evaluation of the business as usual scenario.

Applying and assessing additionality has been studied closely over the past two decades. Figure 1 below, adapted from Rossetto [62] and Baxter and Gilligan [6], illustrates the impact of additionality in the context of a greenhouse gas emission reduction project, where the emissions of the project scenario are below the baseline.

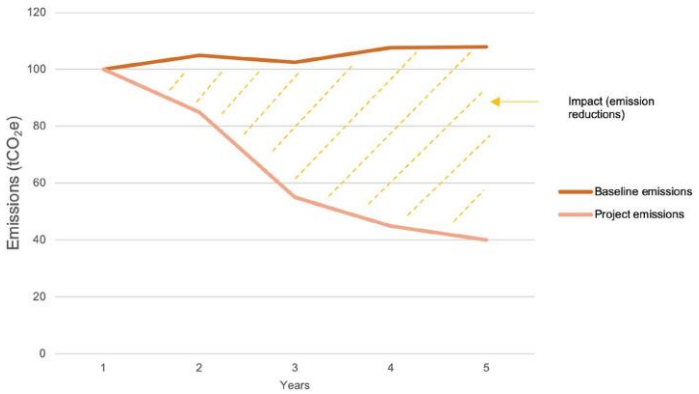


Fig. 1 Illustrative example of the impact of a greenhouse gas emission reduction project that is additional. Source: Adapted from Rossetto [62] and Baxter and Gilligan [6], Page 6

In such cases, provide the project is proven to be a genuine departure from business as usual, impact is the difference between the baseline and project emissions.

A common form of additionality demonstration used under the CDM was *barrier analysis*, whereby proponents could seek to demonstrate that another barrier, such as unfamiliarity of new technology, prevented its deployment.

Another form was *financial additionality*, which asserts that project proponents make investment decisions for lower emissions alternatives based on the price signal of the revenue – or carbon finance – available through the CDM. While laudable, financial additionality became a highly scrutinised and criticised practice. Schneider [67] evaluated 93 registered CDM projects suggests that not all claims are substantiated with credible evidence of financial additionality. Streck [75] acknowledged that testing for financial additionality will always be controversial, though steps can be taken to reduce controversy by maintaining detailed records of investment decision-making.

The aim of financial additionality is to demonstrate that a project fails to meet an investment hurdle rate without inclusion revenues from carbon finance; and thereby the default scenario is that the status quo prevails with a higher emissions baseline. Figure 2, adapted from Rossetto [62], illustrates how carbon finance allows an energy generation project's modelled return on equity to be increased above a hurdle rate of return. In other words, before carbon finance revenues are considered, the project return is insufficient to meet the hurdle rate and therefore, assuming rational investment decision-making, would not proceed. A project is considered financially additional if new revenues support its return to the extent it can achieve a nominal investment hurdle rate. Figure 2 illustrates the message that the records identified by Streck [75] would need to convey.

Carmichael et al. [12] highlighted how critical internal rate of return benchmark analysis is to determining financial additionality based on a windfarm project case study. Project-level investment decision-making integrates different sensitivities, where the revenues that projects are able to generate are assigned probabilities. In this respect, carbon finance can become important at the margin of meeting a project's investment hurdle rate. A decision to not register a project to generate carbon finance revenues is, in effect, assignment of 100% probability that it will generate zero revenues from this item over its lifespan. However, under certain scenarios of probability, the revenues are enough to move the project's return above a nominal hurdle rate.

Dutschke and Michaelowa [21] drew attention to the potential for CDM projects to receive funding through other concessional sources such as ODA. This raised a concern that the CDM incentive, which was a *revenue support mechanism*, may lead to diversions of ODA, a cost of *capital support mechanism*. The CDM Executive Board [14] eventually made it a condition of participation in the CDM that projects must not result in diversions of ODA. Rossetto [62] and then again [63] pointed out that a project's participation in multiple support mechanisms – revenue support, cost of capital support and negative externality levies – may not be mutually exclusive. Notwithstanding, Michaelowa et al. [48] suggested that project level additionality assessment under Article 6.4 continue to use financial additionality.

3.4 Project-based mechanisms in the context of Australia

The final section of the literature review considers the application of project-based mechanisms in Australia. The primary revenue support mechanism for which waste management projects are eligible is the Carbon Credit (Carbon Farming) Act 2011 (*carbon market*), which produced a carbon credit known as an Australian

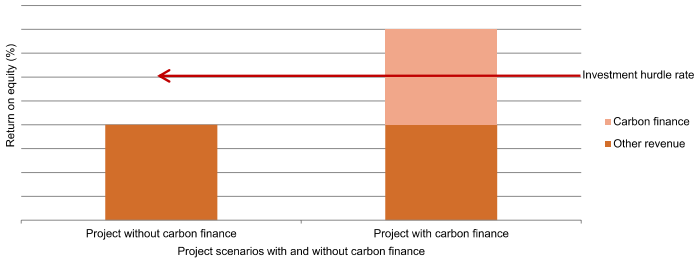


Fig. 2 Illustration of how carbon finance impacts project financial performance by raising returns above hurdle rates. Source: Rossetto, D. (2014). Case studies of climate resilience in urban areas and their funding UNFCCC Standing Committee on Finance Annual Forum – Montego Bay, Jamaica, 21 & 22 June 2014. Montego Bay, UNFCCC, Page 14

Carbon Credit Unit (ACCU). Under the carbon market, the following kinds of projects are eligible to generate carbon credits known as Australian Carbon Credit Units (ACCU): (1) Capture and destruction through combustion of fugitive methane emissions occurring at coal mines, (2) Reductions in the emission-intensity of various forms of transport, (3) Energy efficiency projects and programs implemented either as single projects or aggregated programs at commercial and industrial facilities, (4) Capture and combustion of landfill gas and agricultural waste, (5) Alternative treatment of organic waste, (6) Capture and combustion of biogas from wastewater, (7) Methods for the land sector, including increasing soil carbon, reducing livestock emissions, expanded opportunities for environmental and carbon sink plantings and reforestation and (8) Other methods that result in emissions reductions that take place in facilities that are required to report under the National Greenhouse and Energy Reporting Act. Of the above, methods (4) and (5) are the primary opportunities connected to waste.

For much of its history, demand for ACCUs in the domestic carbon market has relied on a government procurement program known as the Emission Reduction Fund (ERF). Clarke et al. [16] illustrated the budget allocated for the ERF provides about 50 per cent of that required to meet Australia's greenhouse gas abatement commitments. Nong and Siriwardana [52] highlighted the limitations of public procurement to achieve Australia's emission reduction goals and the need to find market-based means of stimulating demand.

White [82] illustrated the emergence of private demand for ACCUs to replace the ERF approach in Australia, beginning with voluntary market demand. The Australian Government [5] subsequently acknowledged the need for private compliance demand and published Safeguard Mechanism policy reforms. Figure 3 provides voluntary private and state and territory government demand for ACCUs during the period 01/01/2019 to 31/03/2022 along with the reason for cancellation.

Notwithstanding, the environmental integrity of Australian carbon market has been the focus of scrutiny, in particular waste to energy projects. Baxter and Gilligan [6] drew attention to the fact that waste to electricity generation projects also have the opportunity to generate electricity, which in turn has the potential to generate tradable certificates under the Renewable Energy (Electricity) Act 2001 (*renewable energy certificate market*). In effect, this provides waste to electricity project operators with an opportunity to produce three different forms of revenue – electricity, renewable energy certificates and carbon credits – which led to questions about additionality for the purposes of the carbon market.

MacIntosh [40] criticised the additionality of ACCUs issued to waste to energy projects on the basis of marginal costs and operational decisions, rather than consideration of investment decisions. The Emissions Reduction Assurance Committee [22] responded to criticisms raised by MacIntosh stating that ACCU revenues were needed but stopped short of providing a detailed

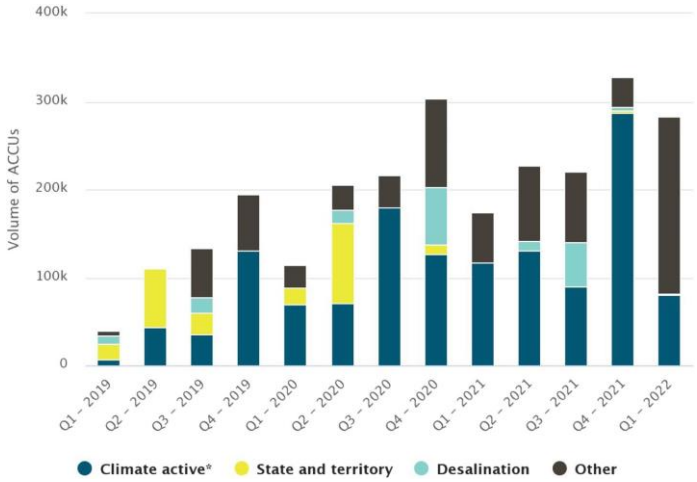


Fig. 3 Voluntary private and state and territory demand for ACCUs and reason for cancellation. Source: Clean Energy Regulator

explanation why. This was a similar the conclusion of Chubb et al. [15] who undertook a review into the environmental integrity of the Australian carbon market.

Australian carbon market projects also have access to other support mechanisms including cost of capital support. The primary support comes through the Clean Energy Finance Corporation (CEFC), which is a financial institution established under federal legislation that provides loans and investments to improved waste management and resource recovery projects. Geddes et al. [26] noted that one of the main roles of the CEFC, similar to state-sponsored green banks in other countries, is to "*de-risk projects*" and "*crowd-in additional finance*" (Page 168) - including through the provision of cost of capital support. The CEFC and Arup [17] revealed that there was a healthy future pipeline of energy from waste projects in Australia that would involve diversion of waste from landfill.

Australia also has a number of negative externality levies that influence the waste sector and act as incentives for resource recovery. Landfill charges are established by each state on an individual basis, though there are variations as can be seen in Table 2 below.

In principle, these charges provide an incentive to recover resources, though the Clean Energy Finance Corporation and Arup [17] highlight that recovery businesses must still set tipping fees competitively with respect to these levies. Wu et al. [83] noted that firms may arbitrage the different landfill charges leading to mobility of waste in Australia.

Finally, Australia has introduced from 2020 prohibitions on the export of paper, plastics, glass and tyres [19]. While this is a regulatory solution, it can also provide an incentive for resource recovery that, in turn, may lead to higher levels of retention of social and economic benefits within Australia [84].

3.5 Summary of the literature review

The preceding literature covered topics from waste management and climate policy, market-based incentive applications in the context of international mechanisms under the UNFCCC, the concept of additionality and then project-based mechanisms in the context of Australia, relevant to addressing the research questions. The review revealed that very little work has been done on analysing the impact of parallel participation in one or more forms of the support mechanisms on project additionality. This is a matter of importance not only to the Australian carbon market but also to other countries, who are seeking to utilise international and domestic incentive mechanisms to achieve emission reduction and waste management goals.

Table 2 Summary of landfill charges across Australian states

State	Metropolitan	Regional
New South Wales	$146/tonne	$84/tonne
Queensland	$80/tonne	$80/tonne
South Australia	$143/tonne	$71/tonne
Tasmania	$20/tonne	$20/tonne
Victoria	$125/tonne	$110/tonne
Western Australia	$70/tonne	$70/tonne

Source: Clean Energy Finance Corporation and Arup [17], Page 19

4 Methodology

The methodology was designed to explore answers to the research question posed in Section 1: *How important are revenue generation mechanisms relative to the others to incentivise improvements in sustainable waste management*? To respond to this research question, two sub-questions were formulated as follows: (1) How extensively are waste sector abatement opportunities represented so far within those that have generated ACCUs? (2) What is the capitalised contribution to equity returns of ACCU revenues over a project's crediting period?

4.1 Design

Research design was established to respond to each of the sub-questions as outlined below:

> *Sub-question 1. How extensively are waste sector abatement opportunities represented so far within those that have generated ACCUs?*
> To answer this question, longitudinal analysis was used to examine projects registered under the Australian Carbon Credit (Carbon Farming) Act 2011 over the 10-year period covering the financial years 2012–13 to 2021–22 to determine the relative share of waste projects in generating ACCUs and the contributions made by projects using different waste methods. Waste methods used were then compared with the potential for resource recovery and other abatement projects at higher stages in the waste hierarchy to determine the extent to which project deployed to date are comprehensive.
> *Sub-question 2. What is the capitalised contribution to project equity returns of ACCU revenues generated over a project's crediting period?*
> To answer this question, a financial model was used to examine the impact of ACCU revenues on project equity returns under different scenarios that tested sensitivities of two separate theoretical projects – *Project one* being a 2 MW biogas cogeneration plant and *Project two* being a 30 MW energy from waste project—under different ACCU price levels and in different states of Australia connected to the National

Electricity Market (NEM) using average wholesale electricity prices across those states based on the outcomes in the 2020/21 and 2021/22 financial years, renewable energy certificate price levels, loan to value ratios and terms of debt financing. The projects were selected to represent the two main methods of producing energy from organic waste: anaerobic decomposition and incineration.

These projects were selected because they deploy electricity generation technologies, meaning they have several revenue streams (electricity and LGCs). They also both involve diversion of waste from landfill and are, by consequence, operating in resource recovery; at higher stages in the waste management hierarchy than landfilling. They represent the next generation of emissions reductions (moving beyond landfill gas to energy) achievable within the waste management sector. This will help to address the gap identified in the literature, by allowing a study into the impact of parallel participation in one or more support mechanisms on project additionality.

4.2 Data collection

Data was collected separately to respond to each of the approaches, as described below:

Sub-question 1. How extensively are waste sector abatement opportunities represented so far within those that have generated ACCUs?

For the longitudinal analysis, data was collected from the Australian Clean Energy Regulator and sorted by method used, which included issued ACCU volumes by vintage year for each project. During the period 31 December 2012 and 30 June 2022, there had been 124 million ACCUs issued from 1,244 active and registered projects with 256 others revoked. Table 3 below provides total ACCU issuance during the period 31/12/2012 to 30/06/2022 with an annual breakdown of issuance over this timeframe, which was the broader data pool on which the analysis is based.

Sub-question 2. What is the capitalised contribution to project returns of ACCU revenues generated over a project's crediting period?

In order to carry out the analysis using the financial model, data was collected on the following parameters: (a) the capital costs and (b) operation and maintenance costs of the hypothetical project, as well as (c) the average wholesale electricity prices by state, (d) the average renewable energy certificate prices and (e) broad terms and conditions for the debt financing. Finally, as the sensitivities were tested based on ACCU prices, final data set (f) was used. Historical data, rather than forecasts whose accuracy is difficult to verify, were used as the basis for the data parameters (a) to (f).

Table 3 Total ACCU issuance during the period 31/12/2012 to 30/06/2022

Financial year	Total ACCUs issued
2021–22	16,508,527
2020–21	16,466,275
2019–20	15,476,458
2018–19	13,663,409
2017–18	12,207,903
2016–17	13,151,991
2015–16	10,719,735
2014–15	9,318,106
2013–14	4,380,473
2012–13	1,750,179
Total	113,643,056

Source: Clean Energy Regulator, 12 April 2023

Data parameters (a) and (b) were taken from the Australian Energy Market Operator's Cost and Technical Parameter Review and are based on the theoretical projects defined [29] (Table 4).

Data parameter (c) was sourced from the Australian Energy Regulator and encompassed average annual wholesale electricity prices during the 2020/21 and 2021/22 financial years for states connected to the National Electricity Market (NEM), including New South Wales (NSW), South Australia, Victoria, Queensland and Tasmania, as presented in Table 5 below.

Data parameter (d) was obtained from the Clean Energy Regulator based on LGC spot prices over the same period as the wholesale electricity prices above, which is 01/07/2020 through to 30/06/2022. During this period, there was some volatility with prices going as low as AUD $30 per certificate and reaching the AUD $50 mark at times. As the LGC price is not a sensitivity parameter flexed for the results presented in Section 5, the average of these prices was used for the analysis, which was AUD $41.25 per certificate.

For data parameter (e), the broad terms and conditions of debt financing were based on a classical non-recourse project finance structure in which the lender(s) secures the loan against the assets of the project and not the assets of the sponsor. The amortisation profile for the loan was selected as 20 years on a foncier repayment schedule, which means that the entire loan is discharged net of interest margin payments in 12 equal amounts each year.

Table 4 Parameters of the two theoretical projects

Parameter	Project one (Biogas)	Project two (Energy from waste)
Technology	Complete system with feedstock logistics, pre-treatment, digesters, gas management, CHP units, heat recovery, electrical generation, equipment & balance of plant.	Incineration (mass burning) with reciprocating grate and mechanical draft cooling tower.
Installed capacity (MW)	2 MW	30 MW
Fuel	Agricultural residues, energy crops, food waste, manures, sewage, municipal solid waste	Solid waste
Capital cost	AUD $28.6 million, including land.	AUD 594.94 million, including land.
Operation & maintenance cost	AUD $ 1.85 million per year.	AUD 6.4 million per year
Annual electricity generation	16,700 MWh per year.	207,675 MWh per year
Economic life	20–25 years	30 years
Investment evaluation period	20 years	20 years

Source: Australian Energy Market Operator 2022 Cost and Technical Parameter Review

Table 5 Average annual wholesale electricity prices during the 2020/21 and 2021/22 financial years (AUD)

Financial year / state	NSW	Queensland	South Australia	Tasmania	Victoria
2020–21	72	66	53	45	51
2021–22	144	178	125	90	104

Source: Australian Energy Regulator

Table 6 ACCU auction results including contracted volumes and clearing prices

Auction	Date	Volume	Price (AUD)	Optiona
1	April 2015	47,333,140	$13.95	No
2	November 2015	44,861,010	$12.55	No
3	April 2016	45,949,842	$10.23	No
4	November 2016	26,668,883	$10.69	No
5	April 2017	8,805,722	$11.82	No
6	December 2017	7,803,535	$13.08	No
7	June 2018	6,323,594	$13.52	No
8	December 2018	3,267,279	$13.87	No
9	July 2019	59,000	$14.17	No
10	March 2020	1,424,771	$16.14	Yes
11	September 2020	6,284,717	$15.74	Yes
12	April 2021	6,623,286	$15.99	Yes
13	October 2021	6,840,577	$16.94	Yes
14	April 2022	7,593,036	$17.35	Yes

Source: Clean Energy Regulator, 16 June 2023

[a] The fifth column with the heading *option* refers to the introduction of a right for successful proponents that would allow them to exit contracted arrangements with the ERF and sell ACCUs instead on the market. In effect, this is a *put option* underwritten by the ERF

While it is somewhat unusual for private sector project lenders to make debt available on a 20-year tenor, the equity contribution of the sponsor(s) was set at 50% rather than the more typical 30%. As analysis of project returns was forward-looking, the sensitivity of returns was modelled based on the most recent lending rates to medium and large businesses published by the Reserve Bank of Australia, the nation's central bank, being 5.75% and 4.93%. These rates are for corporate lending not non-recourse finance, though the lower rate illustrates the concessional rate that would apply to a *cost of capital support mechanism*.

For data parameter (f), ACCU data was initially obtained from the Clean Energy Regulator that illustrated the ACCU prices and forward transaction volumes that emerged from the fourteen Emission Reduction Fund auctions held between April 2015 and April 2022. This data is presented in Table 6.

Separate data tracking the secondary market prices between the period 01/07/2021 and 31/01/2023 was also considered, which showed considerable volatility and variation in pricing from the auction results. In particular, there was a lowest price of approximately AUD $20/t at the beginning of July 2021 and a high of just above AUD $55/t in January 2022, all of which are above the highest price recorded at auction of AUD $17.35/t. Given that secondary market prices are more volatile than the auctions, sensitivities of AUD $0 as if there were no carbon price at all (*Scenario one*), $17.35/t the highest and most recent auction price (*Scenario two*) and $50/t (*Scenario three*) were considered. In addition to parameters (a) to (f), saved landfill charges – acting as a form of negative externality levies - were also included at the regional rates by state provided in Table 2. This assumes that proponents would have sought to find an alternative to metropolitan charges.

5 Results

The response to sub-question one (*How extensively are waste sector abatement opportunities represented so far within those that have generated ACCUs?)* revealed in the first instance that waste methods have so far generated almost a third (38.6 million, 31%) of the ACCUs issued between 01/07/2012 and 30/06/2022. The largest producers of ACCUs over the timeframe have been vegetation methods at just over 69.3 million. The full breakdown is shown in Fig. 4 below.

Within the waste methods, the predominant source of ACCU generation were methods connected to the generation of electricity from landfill gas, which produced over 34.5 million of the credits issued during that timeframe. The remaining 4.1 million credits were generated through alternative waste treatment, commercial and industrial wastewater and separated organic waste methods, which amounts to just over 10% of the total. These figures are illustrated in Fig. 5. With nearly 90% of the total issued credits being from landfill gas to energy projects - which utilises anaerobic digestion to convert energy in the waste into methane which can then be used for power generation by combustion - it is difficult to conclude that the full array of resource recovery and abatement projects is making a substantial contribution as of 30/06/2022, even if landfill gas methods are making up almost one third of the supply side of the market.

The response to sub-question one (*What is the capitalised contribution to project equity returns of ACCU revenues generated over a project's crediting period*?), results of the equity return analysis are presented in Figs. 6 and 7 below. In the results, project one and two consistently return positive pre-tax equity return results in most states using average price data across 2020–21 and 2021–22. Where equity returns are negative, it means that the project's cash flow has not been able to return the invested equity within the 20 year timeframe though it may be able to do so if one considers cash flows beyond 20 years. Where the returns are shown as 0.00%, these were cases where the project had no chance of delivering a positive equity return. Pre-tax equity returns are marginally superior when lower interest rates apply, which is logical given that less project revenue is needed for debt service and more can be dedicated to repaying shareholders. Projects one and two are generally more viable when 2021–22 average wholesale electricity prices are used, given that these were considerably higher across all states compared to 2020–21. The state where a project is based can affect pre-tax returns due to the variability in wholesale electricity prices. ACCU revenues, when not zero, contribute between 2–10% to pre-tax equity returns, depending on the project and scenario. Given the volatility in other values such as interest rates and wholesale electricity prices, this may be an important contribution. Having several sources of revenue – wholesale electricity,

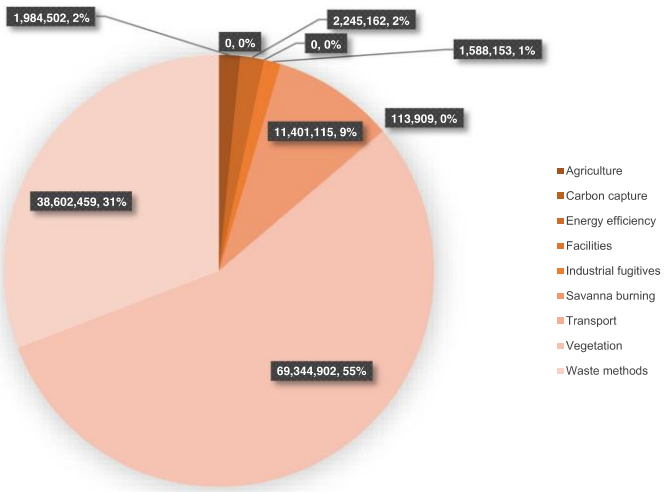


Fig. 4 Breakdown of ACCUs issued between 01/07/2012 and 30/06/2022 by method type. Source: Based on data from the Clean Energy Regulator

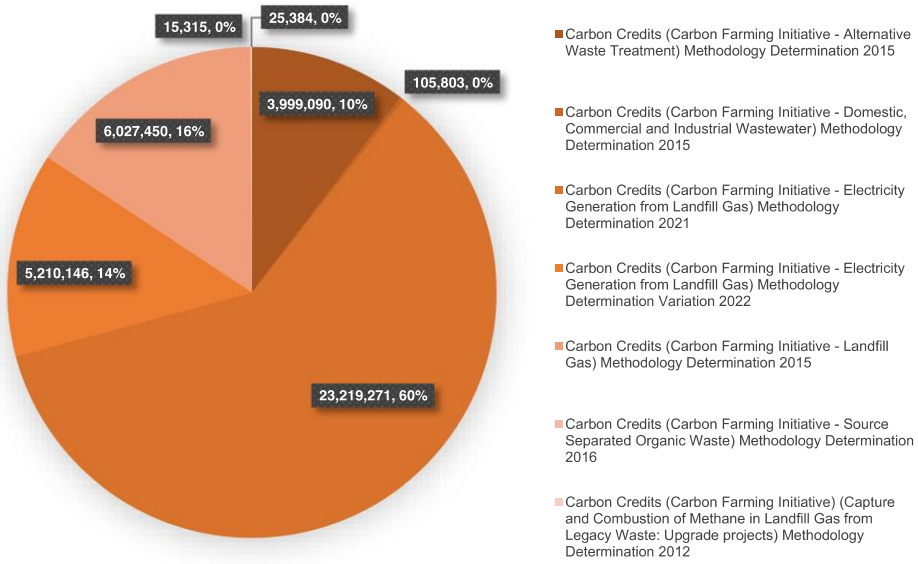
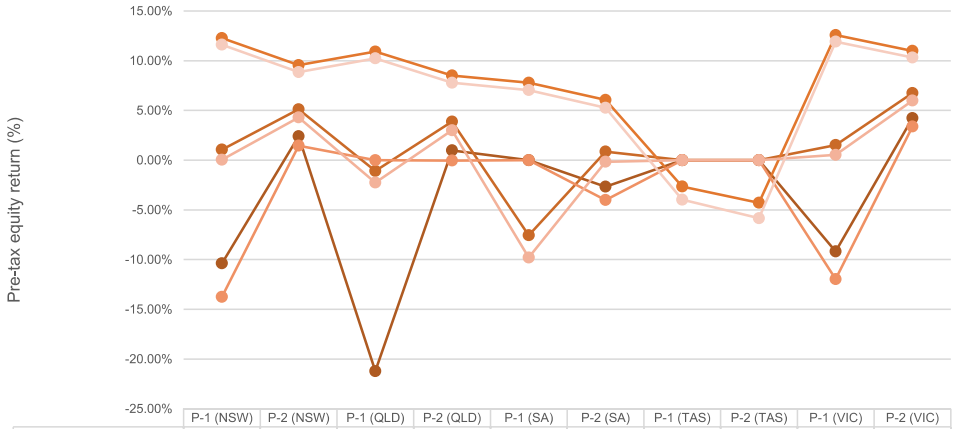


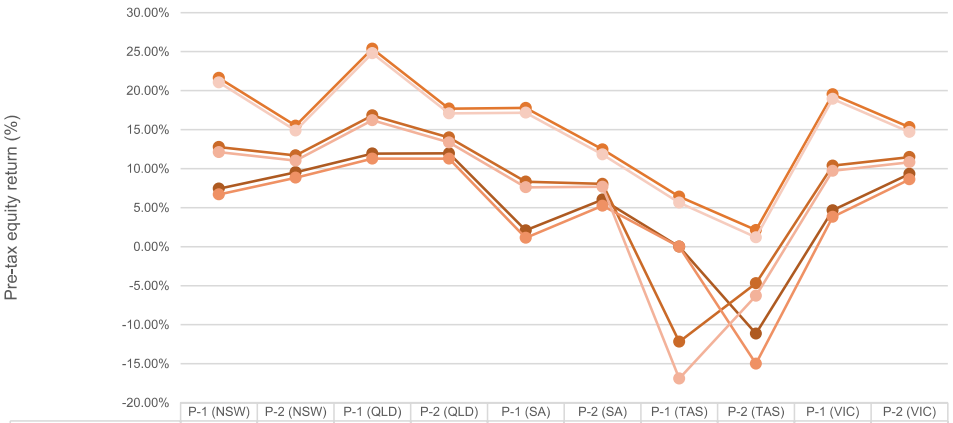
Fig. 5 Breakdown of ACCUs issued between 01/07/2012 and 30/06/2022 by waste method. Source: Based on data from the Clean Energy Regulator



	P-1 (NSW)	P-2 (NSW)	P-1 (QLD)	P-2 (QLD)	P-1 (SA)	P-2 (SA)	P-1 (TAS)	P-2 (TAS)	P-1 (VIC)	P-2 (VIC)
S-1 (lower interest)	-10.38%	2.40%	-21.22%	0.98%	0.00%	-2.67%	0.00%	0.00%	-9.18%	4.23%
S-2 (lower interest)	1.06%	5.12%	-1.08%	3.88%	-7.56%	0.86%	0.00%	0.00%	1.52%	6.75%
S-3 (lower interest)	12.27%	9.56%	10.92%	8.51%	7.78%	6.06%	-2.65%	-4.29%	12.58%	10.99%
S-1 (higher interest)	-13.74%	1.46%	0.00%	-0.04%	0.00%	-4.01%	0.00%	0.00%	-11.97%	3.38%
S-2 (higher interest)	0.05%	4.30%	-2.26%	3.01%	-9.79%	-0.16%	0.00%	0.00%	0.53%	5.99%
S-3 (higher interest)	11.61%	8.86%	10.24%	7.78%	7.04%	5.27%	-3.98%	-5.84%	11.92%	10.32%

Project and state (P-1 represents project one and P-2 project two. S-1, S-2 & S-3 represent ACCU scenarios 1, 2 and 3 respectively)

Fig. 6 Pre-tax equity returns based on forward electricity wholesale prices assumed to be equivalent to NEM average by state in 2020–21



	P-1 (NSW)	P-2 (NSW)	P-1 (QLD)	P-2 (QLD)	P-1 (SA)	P-2 (SA)	P-1 (TAS)	P-2 (TAS)	P-1 (VIC)	P-2 (VIC)
S-1 (lower interest)	7.44%	9.54%	11.94%	11.96%	2.09%	6.03%	0.00%	-11.15%	4.66%	9.33%
S-2 (lower interest)	12.77%	11.69%	16.82%	14.00%	8.33%	8.04%	-12.19%	-4.69%	10.39%	11.49%
S-3 (lower interest)	21.63%	15.50%	25.37%	17.69%	17.78%	12.47%	6.42%	2.14%	19.53%	15.31%
S-1 (higher interest)	6.69%	8.84%	11.28%	11.29%	1.13%	5.24%	0.00%	-15.00%	3.82%	8.62%
S-2 (higher interest)	12.11%	11.03%	16.21%	13.37%	7.61%	7.68%	-16.91%	-6.30%	9.71%	10.82%
S-3 (higher interest)	21.05%	14.88%	24.80%	17.08%	17.17%	11.82%	5.64%	1.19%	18.94%	14.69%

Project and state (P-1 represents project one and P-2 project two. S-1, S-2 & S-3 represent ACCU scenarios 1, 2 and 3 respectively)

Fig. 7 Pre-tax equity returns based on forward electricity wholesale prices assumed to be equivalent to NEM average by state in 2021–22

renewable energy certificates, avoided landfill charges and sales of ACCUs - may also assist in managing volatility across the various sources.

6 Discussion

While waste-sector projects made up nearly one third of the entire supply side of the ACCU market from its inception until the middle of 2022, landfill gas to energy projects made up almost 90% of total supply of waste-based credits. Nearly a quarter of all the issued ACCUs to that point, relied upon the continuation of practice that sends waste to landfill. There is little evidence that the carbon market in Australia is encouraging practices that engage at stages higher up the waste hierarchy that reduce the amount of waste being produced or the degree of resource recovery. This supports the findings of Nisbet et al. [51] that the market finds the lowest hanging fruit,and revenue support incentives are not yet sufficient to encourage mitigation from higher stages of the waste mitigation hierarch.

This paper also addresses the identified need (Refer literature review, Section 3.5) for analysis of the impact of parallel participation in one or more forms of the support mechanisms on project additionality. It showed that, for the hypothetical biogas and energy from waste projects it analysed, both of which involve diversion of waste from landfill, ACCUs can form a significant part of capitalised returns; and therefore may be part of the underlying reason why a private operator would choose to commit to such a project. This is notwithstanding the existence of other revenue streams such as wholesale electricity, avoided landfill charges and renewable energy certificates, this shows that carbon finance is an enabler of more emission reduction potential within the waste management sector, as it can act as an incentive for investment by private actors leading to new and additional project activity. This addresses the issues raised by Baxter and Gilligan [6] and contradict the findings of MacIntosh [40] through illustrating the contribution ACCUs make to ex ante, pre-tax equity returns, rather than assuming that additionality is linked to daily operational decisions once the infrastructure is already in place.

The results, however, reflect outcomes of the sensitivities tested. While renewable energy certificate income is a valid *revenue support mechanism, with* LGC sales of the same magnitude as ACCU revenue, it was not flexed. The contribution to equity returns of the concessional interest rate of 0.82%, being the difference between 5.75% and 4.93%, was less significant. In most cases, the contribution of the *cost of capital support mechanism*, as shown in the results, was less than 1% of pre-tax equity returns. While not tested under sensitivities, the *negative*

externality levy saving of the avoided landfill charges is also material.

The 2–10% range in the contribution of ACCUs often makes up a material component of the capitalised returns. What the paper does not do is comment on the hurdle rate; and whether the carbon contribution is enough to move the project's return from below to above the hurdle rate, nor does it consider the probability assigned to the cash flows and the influence it may have over the investment decision. While Michaelowa et al. [48] advocated for the use of pre-determined values for use in financial additionality assessment - in the context of Article 6 projects under the Paris Agreement but applicable also in this case - this would suggest a return to some elements of the original practice of recording minutes of investment decisions in addition to other safeguards as part of the validation process. While neither the Emissions Reduction Assurance Committee [22] nor Chubb et al. [15] called for this level of assessment to be introduced, it may be a necessary step in future to address stakeholder interest in additionality.

The analysis undertaken finds evidence that, on occasions, multiple incentives as well as multiple revenues may be needed which builds upon the additionality orthodoxy [13, 68]. For example, the financing terms and conditions used for projects one and two are reasonably ambitious and may be difficult to obtain from the commercial market – such as a 20-year loan tenor and an interest margin more closely related to corporate rather than project lending. This would suggest that some capital cost support would assist, such as that available through the CEFC. The existence of multiple revenue streams also provides opportunities for project's to manage their exposure to the inevitable volatility cash flows.

Since the development of voluntary demand for ACCUs and reforms to the Safeguard Mechanism that encourage growth, there have been some signs of impact. In April 2023, Liberty Steel [37] announced development of an Electric Arc Furnace (EAF) for steelmaking in Whyalla, South Australia, which would utilise scrap steel sourced from the local waste market. The announcement made direct reference to the Safeguard Mechanism – which allows private companies to use ACCUs as an offset to emissions liabilities - as a driver, though it also noted that AUD $50 m in grant funding to support the project investment was also being sought. While the Safeguard Mechanism as revenue support is a driver, cost of capital support in grant form is still needed.

This is similar to New Zealand Steel [50] in May, which also announced exploration of an investment into a scrap steel-utilising EAF where a government co-investment is also needed - notwithstanding the carbon price signal created through the New Zealand emissions trading system. This suggests that, for the more ambitious circular economic initiatives higher up the waste hierarchy, revenue support mechanisms are not sufficient to drive investment and need to be complimented by cost of capital mechanisms. It also indicates the ambition embedded within the carbon markets is not yet enough to become the sole driver of circular investment.

This is a significant finding for countries under the Paris Agreement, as it implies the need for complimentary measures at national level to support revenues obtainable from participation in the Article 6.4 mechanism. In addition to conditional and unconditional greenhouse reduction commitments, NDCs also set out the mixture of domestic complimentary policies that countries intend to implement to achieve those goals. This is an important insight for countries such as those previously shown in Table 1 of this study that intend to use international and domestic market mechanisms – and potentially combinations of both - to achieve their targets.

7 Conclusion

Creating sustainable and effective incentives to help businesses transition towards more circular, lower waste and less greenhouse gas intensive practices is a significant challenge for policy makers and managers. This research has identified that a large proportion of carbon credits issued in Australia have been generated by landfill to electricity projects, which effectively rely on the continuation of landfilling. More ambition is needed to realise the potential of circular solutions that reduce, recover and utilise waste before disposal.

While carbon markets have allowed many years of experience with these incentives to build, there has been a general understanding that projects accessing multiple revenue sources was an indicator of non-additionality. In the orthodoxy of international climate change cooperation, simultaneous access of climate finance (as a cost of capital support mechanism) and carbon markets (as a revenue support mechanism) by projects has been discouraged and even precluded over the last 20 years. Pressure has also grown on governments to create domestic revenue support mechanisms and reduce reliance on international carbon markets. This study provides quantitative illustration of the relative impact of revenue support programs - in cases where projects are able to access multiple streams and potentially also cost of capital support – on pre-tax equity returns. As more countries seek to leverage market-mechanisms for the transformation of waste management practices and the achievement of national climate targets and NDCs, this provides an important inflexion point. It illustrates how a project can be financially additional even if it accesses multiple support mechanisms or incentives, though it may necessitate

a return to the practice of validating the investment decision-making process – as was once common in the CDM - on a case-by-case basis to underscore environmental integrity.

These findings are particularly significant for policy makers and business managers; as they show that simultaneous access to one or more support mechanism does not necessarily invalidate its additionality and, in some cases, can be desirable and essential. The potential policy and practice applications are wide in scope. These include the ongoing international efforts to define modalities for the new Article 6.4 mechanism under the Paris Agreement, reforms are considered for developing countries' access to climate finance (including, but not limited to, the Bridgetown Initiative 2.0 (The Bridgetown Initiative 2.0: https://www.un.org/sustainabledevelopment/blog/2023/04/press-release-with-clock-ticking-for-the-sdgs-un-chief-and-barbados-prime-minister-call-for-urgent-action-to-transform-broken-global-financial-system/)); and individual countries seek to optimise domestic carbon market mechanisms so they are fit-for-purpose to support NDCs.

Abbreviations

ACCU	Australian Carbon Credit Unit
AUD	Australian Dollar
CDM	Clean Development Mechanism
CEFC	Clean Energy Finance Corporation
ERF	Emission Reduction Fund
LGC	Australian Large-scale Renewable Energy Certificate
MW	MegaWatt
MWh	MegaWatt Hours
NDC	Nationally Determined Contribution
NEM	National Electricity Market
NSW	New South Wales
ODA	Official Development Assistance
P-1	Project One
P-2	Project Two
QLD	Queensland
SA	South Australia
S-1	Scenario One
S-2	Scenario Two
S-3	Scenario Three
TAS	Tasmania
TCFD	Taskforce for Climate-related Financial Disclosure
tCO_2e	Tonnes of Carbon Dioxide-equivalent Greenhouse Gas
UNFCCC	United Nations Framework Convention on Climate Change
VIC	Victoria
WA	Western Australia
WACC	Weighted Average Cost of Capital

Acknowledgements
Not applicable.

Author's contributions
Conception and design of study: DR. Acquisition of data: DR. Analysis and/or interpretation of data: DR. Drafting the manuscript: DR. Revising the manuscript critically for important intellectual content: DR. Approval of the version of the manuscript to be published: DR.

Funding
Open access funding provided by Shanghai Jiao Tong University.

Availability of data and materials
The corresponding author will act on reasonable requests to release some of the restricted data.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Daniel Rossetto.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]School of Architecture and Civil Engineering, Faculty of Sciences, Engineering and Technology, The University of Adelaide, Room 3009, Horace Lamb, North Terrace, Adelaide, SA 5005, Australia.

Received: 6 July 2023 Revised: 17 August 2023 Accepted: 30 August 2023
Published online: 21 September 2023

References

1. Agamuthu P, Khidzir KM, Hamid FS (2009) Drivers of sustainable waste management in Asia. Waste Manage Res 27(7):625–633
2. Allwood JM (2014) Chapter 30 - Squaring the circular economy: the role of recycling within a hierarchy of material management strategies. Elsevier Inc., Amsterdam
3. Amighini A, Giudici P, Ruet J (2022) Green finance: an empirical analysis of the Green Climate Fund portfolio structure. J Clean Prod 350:131383
4. Asare W, Oduro-Kwarteng S, Donkor EA, Rockson MAD (2022) Cost-effectiveness of incentive schemes for waste material resource recovery. Clean Waste Syst 2:100019
5. Australian Government (2023) Safeguard mechanism reforms: position paper. Department of Climate Change Energy the Environment and Water, Canberra
6. Baxter T, Gilligan G (2017) Verification and Australia's emissions reduction fund: integrity undermined through the landfill gas method? Aust J Environ Law 4(Jun 2017):1–29
7. Benachio GLF, Freitas MDCD, Tavares SF (2020) Circular economy in the construction industry: a systematic literature review. J Clean Prod 260:121046
8. Bian R, Zhang T, Zhao F, Chen J, Liang C, Li W, Sun Y, Chai X, Fang X, Yuan L (2022) Greenhouse gas emissions from waste sectors in China during 2006–2019: implications for carbon mitigation. Process Saf Environ Prot 161:488–497
9. Butu HM, Abraham-Dukuma MC, Adeyemi Adeniyi T, Saturnin KTN, Kigha Nsafon BE, Dioha M, Emodi NV (2022) Clean development mechanism: achievements, challenges and moving beyond 2020. In: Climate change alleviation for sustainable progression. Taylor & Francis, Boca Raton
10. Caldecott B (2022) Climate risk management (CRM) and how it relates to achieving alignment with climate outcomes (ACO). J Sustain Finance Invest 12(4):1167–1170
11. Calvet L, Gianfrate G, Uppal R (2022) The finance of climate change. J Corp Finance (Amsterdam, Netherlands) 73:102162
12. Carmichael DG, Lea KA, Balatbat MCA (2016) financial additionality and viability of CDM projects allowing for uncertainty. Environ Dev Sustain 18(1):129–141
13. Carter P, Van de Sijpe N, Calel R (2021) The elusive quest for additionality. World Dev 141:105393
14. CDM Executive Board (2012) Methodological tool: tool for the demonstration and assessment of additionality. UNFCCC, Bonn. Tool 01 (version 07.0.0)
15. Chubb I, Bennett A, Gorring A, Hatfield-Dodds S (2023) Independent review of Australian carbon credit units: final report. D. o. C. C. E. t. E. a. water. Australian Government Publishing Service, Canberra
16. Clarke H, Fraser I, Waschik RG (2014) How much abatement will Australia's emissions reduction fund buy? Econ Pap (Econ Soc Aust) 33(4):315–326

17. Clean Energy Finance Corporation and Arup (2021) Energising resource recovery: the Australian opportunity. In: Investment outlook. Clean Energy Finance Corporation, Sydney
18. Coase RH (1960) The problem of social cost. J Law Econ 56(4):837–877
19. Council of Australian Governments (2020) Phasing out waste exports response strategy. Council of Australian Governments, Canberra
20. Deryugina T, Moore F, Tol RSJ (2021) Environmental applications of the Coase Theorem. Environ Sci Policy 120:81–88
21. Dutschke M, Michaelowa A (2003) Development aid and the CDM - how to interpret "financial additionality." Environ Dev Econ 11:235–246
22. Emissions Reduction Assurance Committee (2022) Emissions Reduction Assurance Committee findings on the Emissions Reduction Fund's landfill gas generation method. Clean Energy Regulator, Canberra
23. Fowler HW, Fowler FG, Sykes JB (1976) The concise oxford dictionary of current English. Clarendon Press, Oxford
24. Frank MZ, Shen T (2016) Investment and the weighted average cost of capital. J Financ Econ 119(2):300–315
25. Gama AMCDF, Jucá JFT, Firmo ABL (2023) Greenhouse gas mitigation scenarios in the solid waste sector for compliance with the Brazilian NDC: case study of the Recife metropolitan area, Brazil. Waste Manag Res. 734242X231168053-231734242X231168053. https://doi.org/10.1177/0734242X231168053
26. Geddes A, Schmidt TS, Steffen B (2018) The multiple roles of state investment banks in low-carbon energy finance: an analysis of Australia, the UK and Germany. Energy Policy 115:158–170
27. Ginga CP, Ongpeng JMC, Daly MKM (2020) Circular economy on construction and demolition waste: a literature review on material recovery and production. Materials 13(13):2970
28. Gómez-Sanabria A, Kiesewetter G, Klimont Z, Schoepp W, Haberl H (2022) Potential for future reductions of global GHG and air pollutants from circular waste management systems. Nat Commun 13(1):106–106
29. Halder P, Wallace K (2022) Costs and technical parameter review 2022. Australian Energy Market Operator, Brisbane
30. Hervés-Beloso C, Moreno-García E (2021) Revisiting the Coase theorem. Econ Theory 73:421–438
31. Hua C, Liu C, Chen J, Yang C, Chen L (2022) Promoting construction and demolition waste recycling by using incentive policies in China. Environ Sci Pollut Res Int 29(35):53844–53859
32. Jiménez-Rivero A, García-Navarro J (2017) Exploring factors influencing post-consumer gypsum recycling and landfilling in the European Union. Resour Conserv Recycl 116:116–123
33. Kapoor V, Medha M (2021) Assessment of mechanisms and instruments of climate finance: a global perspective. In: Singh P, Verma P, Perrotti D, Srivastava KK (eds) Environmental sustainability and economy. Elsevier, Amsterdam, pp 297–324
34. Kellenberg D (2015) The economics of the international trade of waste. Annu Rev Resour Econ 7:109
35. Kuyper J, Schroeder H, Linnér B-O (2018) The evolution of the UNFCCC. Annu Rev Environ Resour 43(1):343–368
36. Liang T, Wang S, Lu C, Jiang N, Long W, Zhang M, Zhang R (2020) Environmental impact evaluation of an iron and steel plant in China: normalized data and direct/indirect contribution. J Clean Prod 264:121697
37. Liberty Steel (2023) Liberty Steel in Whyalla announces the phase out of coal-based steelmaking with purchase of a low carbon emissions electric arc furnace. GFG Alliance, Whyalla
38. Lo AY, Cong R (2022) Emission reduction targets and outcomes of the Clean Development Mechanism (2005–2020). PLoS Clim 1(8):e0000046
39. Luukkonen T (2000) Additionality of EU framework programmes. Res Policy 29(6):711–724
40. MacIntosh A (2022) The Emissions Reduction Fund's landfill gas method: an assessment of its integrity. The Australian National University, Canberra
41. Magrini C, Dal Pozzo A, Bonoli A (2022) Assessing the externalities of a waste management system via life cycle costing: the case study of the Emilia-Romagna Region (Italy). Waste Manag (Elmsford) 138:285–297
42. Mahpour A (2018) Prioritizing barriers to adopt circular economy in construction and demolition waste management. Resour Conserv Recycl 134:216–227
43. Maqsood T, Shooshtarian S, Wong PSP, Khalfan M, Yang RJ (2021) The capacity of existing C&D waste end-markets in Australian jurisdictions. Research report. SBEnrc P1.75 Creation and Stimulation of End-Markets for Construction and Demolition Waste, Melbourne
44. Martínez JH, Romero S, Ramasco JJ, Estrada E (2022) The world-wide waste web. Nat Commun 13(1):1615–1615
45. Matheson T (2022) Disposal is not free: fiscal instruments to internalize the environmental costs of solid waste. Int Tax Public Financ 29(4):1047–1073
46. Mazzanti M, Marin G, Mancinelli S, Nicolli F (2015) Carbon dioxide reducing environmental innovations, sector upstream/downstream integration and policy: evidence from the EU. Empirica 42(4):709–735
47. Mhatre P, Gedam VV, Unnikrishnan S, Raut RD (2023) Circular economy adoption barriers in built environment- a case of emerging economy. J Clean Prod 392:136201
48. Michaelowa A, Hermwille L, Obergassel W, Butzengeiger S (2019) Additionality revisited: guarding the integrity of market mechanisms under the Paris Agreement. Clim Policy 19(10):1211–1224
49. Michaelowa A, Shishlov I, Brescia D (2019) Evolution of international carbon markets: lessons for the Paris Agreement. Wiley Interdiscip Rev Clim Change 10(6):e613-n/a
50. New Zealand Steel (2023) New Zealand Steel partners with government in $300M EAF co-investment. Bluescope Steel, Sydney
51. Nisbet EG, Fisher RE, Lowry D, France JL, Allen G, Bakkaloglu S, Broderick TJ, Cain M, Coleman M, Fernandez J, Forster G, Griffiths PT, Iverach CP, Kelly BFJ, Manning MR, Nisbet-Jones PBR, Pyle JA, Townsend-Small A, al-Shalaan A, Warwick N, Zazzeri G (2020) Methane mitigation: methods to reduce emissions, on the path to the Paris Agreement. Rev Geophys 58(1):n/a
52. Nong D, Siriwardana M (2017) Australia's Emissions Reduction Fund in an international context. Econ Anal Policy 54:123–134
53. O'Dwyer B, Unerman J (2020) Shifting the focus of sustainability accounting from impacts to risks and dependencies: researching the transformative potential of TCFD reporting. Account Audit Account J 33(5):1113–1141
54. Papastamoulis V, London K, Feng Y, Zhang P, Crocker R, Patias P (2021) Conceptualising the circular economy potential of construction and demolition waste: an integrative literature review. Recycling (Basel) 6(3):61
55. Peng Z, Lu W, Webster C (2022) If invisible carbon waste can be traded, why not visible construction waste? Establishing the construction waste trading 'missing market.' Res Conserv Recycl 187:106607
56. Plöchl C, Wetzer W, Ragoßnig A (2008) Clean development mechanism: an incentive for waste management projects? Waste Manage Res 26(1):104–110
57. Porter ME (1990) The competitive advantage of nations. Free Press, New York
58. Porter ME, Linde CVD (1995) Toward a new conception of the environment-competitiveness relationship. J Econ Perspect 9(4):97–118
59. Powell JT, Chertow MR, Esty DC (2018) Where is global waste management heading? An analysis of solid waste sector commitments from nationally-determined contributions. Waste Manag (Elmsford) 80:137–143
60. Purchase CK, Al Zulayq DM, O'Brien BT, Kowalewski MJ, Berenjian A, Tarighaleslami AH, Seifan M (2021) Circular economy of construction and demolition waste: a literature review on lessons, challenges, and benefits. Materials 15(1):76
61. Rasheed N, Khan D, Gul A, Magda R (2023) Impact assessment of climate mitigation finance on climate change in South Asia. Sustainability (Basel, Switzerland) 15(8):6429
62. Rossetto D (2014) Case studies of climate resilience in urban areas and their funding. In: UNFCCC Standing Committee on Finance Annual Forum – Montego Bay, Jamaica, 21 & 22 June 2014. UNFCCC, Montego Bay
63. Rossetto D (2017) Defining green finance for climate change. Daily environment report, Bloomberg BNA 227 DEN 18, New York
64. Rossetto D (2019) Carbon markets beyond 2020: achieving breakthrough on Paris Agreement. Bloomberg Law J Environ Energy Rep
65. Rossetto D (2023) The carbon border adjustment mechanism: what does it mean for steel recycling? Sustain Horizons 5(2023):100048
66. Rossi F, Morone P (2023) North–South waste trade: prime example of the circular economy or major environmental threat? Circ Econ Sustain
67. Schneider L (2009) Assessing the additionality of CDM projects: practical experiences and lessons learned. Clim Policy 9(3):242–254
68. Schneider L, La Hoz Theuer S (2019) Environmental integrity of international carbon market mechanisms under the Paris Agreement. Clim Policy 19(3):386–400

69. Schwarz AE, Ligthart TN, GodoiBizarro D, De Wild P, Vreugdenhil B, van Harmelen T (2021) Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. Waste Manag (Elmsford) 121:331–342
70. Shah AV, Srivastava VK, Mohanty SS, Varjani S (2021) Municipal solid waste as a sustainable resource for energy production: state-of-the-art review. J Environ Chem Eng 9(4):105717
71. Shooshtarian S, Caldera S, Maqsood T, Ryley T, Khalfan M (2022) An investigation into challenges and opportunities in the Australian construction and demolition waste management system. Eng Constr Archit Manag 29(10):4313–4330
72. Shooshtarian S, Maqsood T, Khalfan M, Yang RJ, Wong P (2020) Landfill levy imposition on construction and demolition waste: Australian stakeholders' perceptions. Sustainability (Basel, Switzerland) 12(11):4496
73. Söderholm P, Ekvall T (2019) Metal markets and recycling policies: impacts and challenges. Miner Econ Raw Mater Rep 33(1–2):257–272
74. Steffen B (2020) Estimating the cost of capital for renewable energy projects. Energy Econ 88:104783
75. Streck C (2011) Ensuring new finance and real emission reduction: a critical review of the additionality concept. Carbon Clim Law Rev 5(2):158–168
76. Struthers IA, Herraiz L, Muslemani H, Su D, Thomson C, Lucquiaud M (2022) Assessing the negative carbon emissions potential from the Waste-to-Energy sector in Europe (November 25, 2022). Available at SSRN: Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16) 23-24 Oct 2022. International Energy Agency, Lyon
77. Su P, Peng Y, Hu Q, Tan R (2020) Incentive mechanism and subsidy design for construction and demolition waste recycling under information asymmetry with reciprocal behaviors. Int J Environ Res Public Health 17(12):4346
78. Tao H, Zhuang S, Xue R, Cao W, Tian J, Shan Y (2022) Environmental finance: an interdisciplinary review. Technol Forecast Soc Chang 179:121639
79. United Nations (1992) UN framework convention on climate change. U. Nations. UNFCCC Secretariat, Bonn
80. United Nations Environment Programme (2015) Global waste management outlook. United Nations Environment Program & International Waste Management Association, Nairobi
81. United Nations Framework Convention on Climate Change (2023) Clean development mechanism webpage. Retrieved 10 August 2023, from https://cdm.unfccc.int/
82. White RE (2022) The role of soil carbon sequestration as a climate change mitigation strategy: an Australian case study. Soil Syst 6(2):46
83. Wu H, Zuo J, Yuan H, Zillante G, Wang J (2020) Cross-regional mobility of construction and demolition waste in Australia: an exploratory study. Resour Conserv Recycl 156:104710
84. Wu H, Zuo J, Yuan H, Zillante G, Wang J (2023) Investigation of the social and economic impacts of cross-regional mobility of construction and demolition waste in Australia. Resour Conserv Recycl 190:106814
85. Xie J, Xia Z, Tian X, Liu Y (2023) Nexus and synergy between the low-carbon economy and circular economy: a systematic and critical review. Environ Impact Assess Rev 100:107077
86. Yang M, Chen L, Wang J, Msigwa G, Osman AI, Fawzy S, Rooney DW, Yap P-S (2023) Circular economy strategies for combating climate change and other environmental issues. Environ Chem Lett 21(1):55–80

Publisher's Note

Chapter 9. Publication five and statement of authorship

This section presents the publication: *The role of border carbon adjustments and subsidies in incentivising investment: Comparing equivalence in the context of steel recycling and decarbonisation*.

9.1 Statement of authorship

The statement of authorship is provided below in Table 12.

Table 12 – Statement of authorship for publication five

Title of paper:	**The role of border carbon adjustments and subsidies in incentivising investment: Comparing equivalence in the context of steel recycling and decarbonisation.**			
Publication status:	Published		Accepted for publication	
	Submitted for publication	×	Unpublished and unsubmitted work written in manuscript style	
Publication details:	Discover Sustainability (Springer Nature)			
Name of principal author:	Daniel Marc Rossetto			
Contribution to the paper:	Research design, research execution and sole author			
Overall percentage:	100%			
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.			
Signature:				
Date:	14/03/2024			

9.2 Specific aims of the paper

The paper sought to provide a comparison of the magnitude of different forms of incentive – particularly in the area of steel decarbonisation - as had been identified in the literature review. Accordingly, the research was structured to answer the following research question: *What is the equivalence (in NPV and annualised cost/benefit terms) of revenue support/negative externality levies compared with cost-of-capital support measures as an incentive for steel produced using scrap steel feedstocks?*

In order to answer the research question, a forward-looking financial model was prepared to flex the different incentives available to convert a steel plant to EAF technology, thereby allowing it to use scrap steel as a primary feedstock. In principle, the plant could be located in any jurisdiction, on the assumption that it would be exposed in some way to the European Union's CBAM program, either as a plant located in a member state that participates in the EU ETS or as one located in a third country that exports production to the EU. In this case, the baseline scenario is traditional steel production, using Blast Furnace and Basic Oxygen Furnace (BF-BOF) technology.

The financial model is based on investment needed to convert a plant of 1 million tonnes per annum of steel production capacity to EAF technology, flexing sensitivities associated with incorporating the costs and benefits of participation in four kinds of emissions-linked incentive programs. The incentive programs are:

- The EU ETS and associated CBAM program, providing the project sponsor with an incentive to invest to reduce its compliance liability for its production covered under a *negative externality levy* incentive program of this kind.
- Voluntary participation in officially supported export credits, which provides the sponsor *cost-of-capital support* in the form of an extension in debt tenor from 15 to 22 years in exchange for implementation of cleaner technology.
- Voluntary participation in a program equivalent to the IRA's Advanced Industrial Facilities Deployment Program, whereupon the sponsor accesses *cost-of capital support* with up to 50% of the project's capital cost subsidised.
- Voluntary participation in a climate finance program, provides the sponsor *cost-of-capital support* in the form of concessional debt over 15-years in exchange for implementation of the cleaner technology.

9.3 Current citations

The paper has not yet been published, so there are no citations to report.

9.4 Publication five

The paper has not yet been published.

The role of border carbon adjustments and subsidies in incentivising investment: Comparing equivalence in the context of steel recycling and decarbonisation.

Daniel Rossetto (sole author)
School of Architecture and Civil Engineering
The University of Adelaide
Faculty of Sciences, Engineering and Technology
23 November 2023
Word count: [7,761]

Corresponding author:
Daniel Rossetto
Email: daniel.rossetto@adelaide.edu.au
ORCID: 0000-0002-5778-4542
Permanent address: Room 3009, Horace Lamb, North Terrace 5005, South Australia

Chapter 10. Discussion

10.1 Purpose of the chapter

The purpose of this section is to provide a description of the results of the research undertaken and present its significance relative to the body of knowledge that existed, specific to the research question, before this research took place. It sets out the new insights that have emerged through comparison with prior publications relevant to the individual research objectives, as well as the theoretical framework that had previously been presented in Section 2.6 of the Literature Review. It is structured first to provide an overview and interpretation of the results of the study, a comparison of these findings when compared to previous studies, consideration of the overall implications of the results and, finally, a summary.

10.2 Overview and interpretation of results

The research question adopted for this project was: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* Given the importance of the term *incentive* to this question, it is also worth revisiting the fundamental Concise Oxford Dictionary of Current English (1976 p.176) definition of the term as being "*a thing that motivates or encourages someone to do something*". In the case of construction and demolition waste management and set within the context of this research project, the act that one might seek to encourage, or incentivise, is greater recovery and utilisation of waste instead of landfilling and disposal. In effect, the ultimate goal is to move toward the proverbial ideal where one actor's trash becomes another's treasure (Hlousek and McVeigh 2020); and in doing so many of the negative social and environmental externalities associated with construction and demolition waste practices are either reduced or eliminated in the most *efficient* ways possible. When using the term *efficient*, considering that the research is concerned with societal welfare, this refers to societal concepts of *Pareto* and *Kaldor Hicks* efficiency rather than efficiency at the firm level. The key characteristics of and differences between these efficiency concepts were previously described in Section 2.3, which set out the state of the art in assessment of social costs and benefits at the whole-of-society level.

This project sought to answer the research question by breaking the response into five separate objectives. The research results pursuant to each one of these is now discussed in the paragraphs below.

*Define the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation and market-measures that can be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices (**Objective 1**).*

The results in response to this objective stemmed from practitioner interviews carried out and described in Chapter 4. The purpose of the interviews was to validate the relevance of the incentive mechanisms outlined in Section 2.4 of the literature review for the specific context of construction and demolition waste and resource recovery in Australia. Interview participants had been selected on the basis they were in senior- or middle-management positions within organisations that are active participants in the construction and demolition waste ecosystem and the resource recovery industries connected to it. To capture a representative cross-section of entities within the ecosystem and the functional areas, the participation of five different categories of organisation was secured.

The practitioner interviews illustrated that there are many examples of the full spectrum of incentives - including voluntary action, common law, subsidies, regulation, taxation and market-measures – either already in use or considered desirable in future to incentivise resource recovery and utilisation in construction and demolition waste practices. In some cases, interview participants described what appeared to them to voluntary activities that were, in fact, arising due to regulations in other sectors. Participants also discussed current and future programs, which can also impact the level of resource recovery occurring across the construction and demolition and other sectors. This was particularly so for programs linked to the positive externality of reduction of greenhouse gas emissions, such as carbon markets.

In response therefore to the research question (*How can incentives for resource recovery and utilisation in construction and demolition waste be improved?*), a variety of mechanisms were validated for their relevance to construction and demolition waste. Notwithstanding, it became apparent that there is an often complex interaction between underlying regulation and voluntary actions by firms. In some cases, participants would mention what appeared to be voluntary, business-as-usual, initiatives by firms, even though the economic viability of those initiatives was linked either directly or indirectly to the existence of other regulations. A good example was observed in the impact that landfill charges (negative externality levies) have on resource recovery activities.

*Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste (**Objective 2**).*

The results in response to this objective stemmed from the findings of portfolio paper one, presented in Chapter 5. The paper built on the notion that efforts in construction and demolition waste are influenced by policies whose purpose is different from encouraging more resource recovery and utilisation. The study sought to explore whether the EU's CBAM program is likely to drive demand for resource recovery and recycling. It set out to answer a specific research question: *Will CBAM create an incentive for resource recovery and recycling in steel production?* The study applied logic and then longitudinal analysis based on historical prices of steel, scrap steel and emissions units issued in the EU.

The paper illustrated that steel production using electric arc furnace technology, necessary to make use of scrap steel, can deliver a cost advantage over traditional steelmaking methods, though this applies only because the CBAM design will remove the current system of free allocation of EUAs used for steelmakers at risk of carbon leakage. The research therefore revealed evidence that free allocation of carbon allowances mutes the signal to use scrap steel within the EU and, with the removal of this feature under CBAM, the signal will strengthen. By extension, the results allow the conclusion that a program whose main objective includes the reduction of greenhouse gas emissions can, under certain important conditions like the removal of free allocation of carbon allowances, will amplify the incentive to recover waste materials.

This is significant as, once broadly understood, will allow policy makers that are seeking to support circular economy development or other policy goals connected to more sustainable construction and demolition activity to rely on – or reform - programs targeting other policy goals like greenhouse gas reduction. An example emerging from the paper was embodied emission reductions, noted by researchers as requiring financial incentives to become more common practice. The paper also showed how these outcomes can reduce regulatory burden in a context where overregulation is a recognised barrier to better waste management and resource recovery practice.

The theoretical implications of these results are also important, as they illustrate that the initial allocation of property rights does matter. This therefore adds to understanding of the scope and application of Coase's theorem.

Examine the long-term feasibility of international measures – in particular border carbon measures – providing incentives for resource recovery and utilisation in construction and demolition waste practices (***Objective 3***).

The results in response to this objective stemmed from the findings of portfolio paper two, presented in Chapter 6. A fundamental tenet of an incentive program that seeks to create incentives that influence long-term capital allocation is that it be reliable; and not be at risk of substantial modification or repeal during the timeframe needed to generate returns for the project investments that result (Rossetto 2019). For this reason, it is important to examine the long-term feasibility of programs such as CBAM, which might otherwise have a positive impact on resource recovery activities, as had been illustrated in the first portfolio paper entitled *The Carbon Border Adjustment Mechanism: What does it mean for steel recycling?*

Accordingly, the second portfolio paper, entitled *The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector* was carried out to investigate the specific areas in which border carbon mechanisms are vulnerable to challenge in the future? In this respect, the paper considered measures being proposed in both the European Union and United States.

The study illustrated that there are notable similarities between border carbon mechanisms and kinds of impacts on sovereignty that eventually led to the removal of intercontinental aviation from the EU emissions trading system. In other words, it may be sovereignty impacts rather than consistency with World Trade Organisation (WTO) rules that become the point of vulnerability for CBAM. The issue arose because the EU was collecting revenues from aircraft operators for emissions that occurred outside its own airspace. The activities that had been made liable were occurring outside the sovereign territory of the EU. A group of 23 countries, including India, the United States, Nigeria, Saudi Arabia and China, objected to this as a matter of principle. The critical point in the debate arose when those 23 countries communicated several countervailing measures, among which was boycotting the purchase of aircraft made by Airbus, the EU-domiciled manufacturer.

The intercontinental aviation coverage mechanism within the EU emissions trading system was first passed in 2008 and even began operating from 1 January 2012, though it was not repealed for a few years and was first suspended in what became known as the *Stop the Clock* measure – in response to the countervailing measures announced by the group of 23 countries - to allow time for the International Civil Aviation Organisation (ICAO) to work on a global emissions trading system for intercontinental aviation under the auspices of the United Nations. This does not necessarily create a precedent for the CBAM measure, though the policy is still in its early stages of development and there have already been expressions of concern from some countries. The issue of sovereignty in climate policy has become arguably more accentuated since then, as the Paris Agreement of the UNFCCC made in 2015 moved away from the top-down approach of the Kyoto Protocol to the bottom-up development of nationally determined contributions by countries. The final solution for intercontinental aviation was the creation of a global sectoral mechanism for intercontinental aviation under ICAO.

The paper demonstrated the inherently unsettled interactions between international trade and climate policy. The principle of most favoured nation (WTO) used to prejudicial trade policies based on the country of provenance of a particular good contradicts, in many ways, the common but differentiated responsibilities provision of the UNFCCC. Reactions to be developed in third countries will build over time. If the case study of what happened in intercontinental aviation affects CBAM, it raises the question of how concerns could be solved in the context of carbon leakage. The CORSIA program was eventually developed under the auspices of the International Civil Aviation Organisation (ICAO) and replaced the EU ETS as the means of coverage of intercontinental aviation. This may lead to a renewed focus on global sectoral agreements, particularly for internationally traded products like steel.

In response therefore to the research question (*How can incentives for resource recovery and utilisation in construction and demolition waste be improved?*), the paper illustrates the importance that policies implemented to incentivise resource recovery be sustainable in the long term. Private sector actors will find it difficult to plan and implement investments and innovation strategies in cases where there is substantial risk that a policy will be substantially modified or even repealed in future.

Assess the effectiveness of voluntary action by firms to address externalities generated in the construction and demolition waste ecosystem (***Objective 4***).

The results in response to this objective stemmed from the findings of portfolio paper three, indicating several characteristics about the relationship between the sustainability-related disclosures and the development of corporate innovation and performance by firms in the construction and demolition waste ecosystem. Effectiveness of voluntary action by firms to address externalities has been the subject of scrutiny over the last few decades not only by scholars but also in the broader community. Some express doubts over the ability of voluntary action to drive real changes in practice, with firms often preferring instead to communicate externally about what they already do rather than how practices will be or are being changed.

This leads some to conclude that CSR activities and sustainability communication amount to greenwashing. In this context, construction and demolition waste is an interesting sector of focus because there is much scope for improvement but an ongoing debate about whether moving toward better practice ought be the responsibility of firms. Much of the concern is built around perception that better practice is costly and there, unless otherwise incentivised or compelled to do so, firms will not change.

The research presented in paper three revealed that firms in the Australian construction and demolition waste ecosystem, particularly the larger ones including those listed on stock exchanges, are making a concerted effort to embrace many of the global trends toward voluntary sustainability reporting and practice. There was, however, notable volatility in the financial performance of the firms examined. Only one firm demonstrated consistent growth in equity returns over the timeframe, suggesting corporate disclosures on sustainability performance are at best loosely connected to enhanced performance. In addition, it was notable that few of the innovations shared by participants in the interviews are among the activities being reported in sustainability disclosures. It is likely, by consequence, that firms are engaging in innovation and strategic CSR but consider that information commercially confidential, so it is not being reported publicly.

In response therefore to the research question (*How can incentives for resource recovery and utilisation in construction and demolition waste be improved?*), the research revealed that a certain degree of voluntary action may take place as corporate innovation. That kind of innovation, if it is strategic in nature and designed to confer a competitive advantage, may not be disclosed until a new process or product is ready for sales to the marketplace. In other words, the incentive to innovate and change is competitive advantage. The paper illustrates, however, that innovation may lead to the creation of new business activities that occur outside incumbent firms who see advantages in purchasing services from third parties on an outsourced basis. This is somewhat contradictory to the Porter Hypothesis, which supports the idea that higher environmental standards – whether they be applied by regulation or through the voluntary efforts of firms to satisfy consumer need – may drive innovation outside the boundaries of firms.

Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management (***Objective 5***).

The results in response to this objective stemmed from the findings of portfolio paper four, presented in Chapter 8. Section 2.5 of the literature review identified the various forms of economic incentive that can be applied to induce changes in activity among firms - as distinct from regulatory incentives that either prohibit certain activities or mandate others. The mechanisms can be categorised into three main groupings, being revenue support mechanisms, cost of capital support mechanisms and negative externality levies. The principal idea of these mechanisms is that they induce practices that are additional to business-as-usual; a phenomenon that is sometimes described as additionality. In other words, the incentive mechanism was the cause of the change in practice and therefore the beneficial impact can be measured as the difference between the baseline (business-as-usual) scenario and the outcome delivered by the new practice. Traditionally, scholars and practitioners have conceived that the use of incentive mechanism needed to be limited to one only. By extension, if somehow a project or activity sought to benefit from more than one mechanism, it could not be additional. While there had been some regulatory correspondence suggesting that simultaneous access to multiple incentive mechanisms was justified, little scholarly work had been done to quantify this or to explore the relative impact of the different incentives.

It had also been clear from some criticisms of the environmental integrity of some projects that those critics had focused on factors not considered in traditional investment decision-making practice by private firms.

Paper four looked specifically at waste management sector projects in Australia, which is a particularly rich case study area because such projects can access multiple incentive mechanisms. These include avoiding the cost of negative externality levies in the form of landfill charges for waste disposal, cost of capital support through the national green bank, energy sales (where projects involve the use of waste to generate electricity) green certificates from the sale of renewable electricity and the sale of carbon credits issued to projects for the reductions in greenhouse gas emissions achieved in operation. The very existence of so many parallel forms of incentive had led to many scholarly and stakeholder criticisms that questioned their additionality.

Emerging from the study was evidence that, notwithstanding the existence of several potential revenue streams for projects that involve diversion of waste from landfill, carbon market income – specifically that connected to the sale of emission reduction certificates – can add between 2-10% to pre-tax equity returns. In turn, this boost to returns can play an influential role in determining whether a sufficient incentive exists to invest in the project. Therefore, this study reveals that capitalised contribution to returns from the carbon market, based on the sensitivities modelled as part of the empirical component of the research, is greater than that of cost of capital support and of similar magnitude to other revenue streams and the avoided costs of landfilling. This provides credible reason why a private operator would choose to commit to such a project, leading to the conclusion that the existence of multiple incentives does not necessarily invalidate a project or activity's additionality. Moreover, the existence of multiple revenue streams also provides opportunities for project sponsors and firms to manage exposure to volatility in the cash flows. This feature, which lends itself toward risk management, may indeed be a decisive factor in making a positive investment decision.

Another important finding of the paper was that, thus far, there insufficient evidence to show that carbon markets have positively incentivised projects that divert waste from landfill. Most of the projects implemented to date have been landfill gas to electricity projects. Further ambition will be needed to create incentives sufficient to help the sector deliver on its potential to divert waste from landfill altogether in accordance with so-called circular approaches.

10.3 Comparison with previous studies

The following section compares the findings of this research with previously published studies related to construction and demolition waste, resource recovery and to the identified theory. The discussion is subdivided according to its connection to each research objective.

In relation to the first research objective: *Define the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation and market-measures that can be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices.*

The need for economic incentives to influence outcomes in the construction and demolition waste sector, especially as a means of overcoming barriers, has been identified by many scholars. Shooshtarian, Caldera et al. (2022) found that incentives to improve construction and demolition waste management practice were best focused on addressing specific barriers by motivating firms. In this context, overregulation – the existence of excessive amounts of rules that determine what can and cannot be done - and the absence of opportunities trade in waste were notable market failures. Accordingly, the study identified that targets and mechanisms were needed to drive demand for reusing and recycling construction and demolition waste, though it did not specific what mechanisms were needed or how they would increase demand.

Peng, Lu et al. (2022) made the case for a cap-and-trade market for construction and demolition waste, though noting that such a mechanism had never previously been implemented and would therefore involve some risk. The reason for the authors' suggestion was acknowledgement that a market-based solution would lead to lower transaction costs that the alternatives, however recognising that an optimum allocation system for the permits, which would have the characteristics of property rights, was vital.

Asare, Oduro–Kwarteng et al. (2022) found financial incentives were powerful motivators for increased resource recovery as an alternative to landfill in construction and demolition waste management, though the nature of the incentive was important. In this respect, positive incentives that rewarded market participants for practices that generate positive externalities were superior to those that penalise the negative externalities.

The authors recognised that the costs associated with implementing and managing such programs – akin to transaction costs viewed through the societal welfare lens - may represent a barrier to their implementation, though did not propose how such transaction cost dilemmas can be overcome.

Hua, Liu et al. (2022) investigated the efficiency and effectiveness of different tax and subsidy programs – and combinations of the two - to incentivise more sustainable construction and demolition waste practices. The authors concluded that the approach can be used by policy makers in designing optimum programs for real-case implementation. Furthermore, Tong, Yu et al. (2023) found the most efficient approach to incentivising the implementation of urban recycling infrastructure for construction and demolition waste comes from anchoring the programs to capture the carbon emission reduction value.

This thesis, on the other hand, has contrasted these studies by illustrating that the mechanisms that create demand for recovered materials do not need to be designed only for that purpose. In fact, its unique findings include that programs that have other purposes – such as greenhouse gas emission reduction – may provide a dual incentive. This insight is important because it means regulatory burden discussed by Shooshtarian, Caldera et al. (2022) could be eased by aligning goals for incentivising resource recovery with other policies. It revealed that free allocation of permits can impact the results of the program. This is an important theoretical insight as well because Peng, Lu, et al. (2022) had cited Coase's theory as one of the main underpinnings of its conclusions. It illustrated the potential for resource recovery to be incentivised by programs whose main objective was another policy goal – such as greenhouse emission reduction. In such cases, the costs associated with designing and implementing specific programs for construction and demolition waste could either be avoided or made more efficient. It revealed the broader array of alternatives to tax and subsidy programs, while at the same time illustrating the potential for resource recovery and recycling co-benefits derived from other mechanisms. Finally, the study is explicitly unique in identifying the resource recovery co-benefits that can flow from programs whose first purpose is emission reduction. It also defines a broad range of incentive mechanisms, including voluntary action, common law, subsidies, regulation, taxation and market-measures, commonly referred to by industry participants that can capture the emission reduction value of resource recovery and recycling activities in construction and demolition waste.

This finding has implications for market-based management theory, as co-benefits are, in effect, positive externalities that result from a separate activity. In other words, under the normal course of business, a social benefit is generated but the party responsible for its generation does not gain income.

In relation to the second research objective: *Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste.*

Scholars have previously identified the greenhouse gas reduction co-benefits associated with resource recovery practices in construction and demolition waste management. Nußholz, Rasmussen et al. (2020) drew this conclusion, though noted that more sustainable practices were not necessarily being rewarded financially for the positive externalities they generate. Magrini, Dal Pozzo et al. (2022) considered the negative and positive externalities associated with waste management practices in the region of Emilia-Romagna in Italy and noted that of the most important benefits of resource recovery was a reduction in greenhouse gas emissions connected to transport. Economic actors in the sector may be one or more steps removed from the financial, social or environmental benefits that flow from this. In this respect, split incentives across different markets may be limiting the effectiveness of price signals.

Söderholm and Ekvall (2019) identified that policy makers need a deeper understanding of the interactions between various commodity markets and those for secondary or recycled steel, in order to be able to design and then implement enhanced price and quantity based policies to be able to incentivise deeper resource recovery and utilisation practice.

Muslemani, Liang et al. (2021) subsequently identified a range of policy mechanisms that would provide a financial incentive for green steel production through various technological means. The conclusions were based around an assumption that certain industries might be willing to pay, on a voluntary basis, premiums for steel that is demonstrably more sustainable than traditional or business-as-usual steel. The authors identified high-end luxury and heavy duty vehicles as among the most likely markets to pay such a premium voluntarily.

Zhong and Pei (2022) and Struthers, Herraiz et al. (2022) found CBAM, once implemented, is likely to drive income redistribution across the global steel production sector. This redistribution is likely to result in losses in competitiveness in countries where steel production is more emissions intensive. The authors issued a caution for policy makers to beware of unintended consequences in CBAM design, though this was primarily cast in a context where these would be negative.

The first portfolio paper within this doctoral thesis, on the other hand, concluded with the unique finding after examining the interactions of steel, scrap steel and carbon markets in Europe that a specific policy reform to the EU emissions trading system – CBAM – if coupled as planned with progressive removal of free allocation of carbon allowances, would result in a price signal to encourage more use of scrap steel. This would remove the need to rely on voluntary demand for green steel at premium prices, particularly as had been foreshadowed by Muslemani, Liang et al. (2021).

It also showed in a way that had not been done before that some unintended consequences of a mechanism like CBAM, as had been foreshadowed in the studies by Zhong and Pei (2022) and Struthers, Herraiz et al. (2022), under certain design preconditions, could be positive, such as an increase in the incentive for market participants to utilise more scrap steel.

This finding has implications for applications of Coase's theory, as it demonstrates that the initial allocation of a property right does affect the extent to which externalities are internalised and social costs are minimised.

In relation to the third research objective: *Examine the long-term feasibility of international measures – in particular border carbon measures – as a means of providing incentives for resource recovery and utilisation in construction and demolition waste practices.*

Where market interventions are designed and implemented to encourage changes in behaviour by market participants, scholars have noted the importance of the long-term stability and sustainability of the policies, reforms and structures that underpin the interventions (Sandmo 2000, Stavins 2003). Scholarly endeavour has been focused on stability of market-based measures, which seek to influence capital allocation decisions and investment behaviour of private firms (Duc Huynh, Burggraf et al. 2020, Peng, Lu et al. 2022).

Support mechanisms are established for the specific purpose of influencing private investment decisions into long-lived infrastructure (encompassing revenue support, cost of capital support and negative externality levies, as set out in Section 2.5 of the literature review). In this context, *ex-post* modifications to policies or regulations that give the mechanisms their effect can undermine investor confidence. While it is the right of host countries to change regulatory or policy settings to adapt to circumstances that emerge over time, this can undermine the case to invest in new projects. Another possible outcome is that sovereign risk premiums added to investments work against the very nature and purpose of the mechanisms. These items have been considered in detail by scholars over the last 15 years such as Boomsma and Linnerud (2015), Ortino (2018), Zannoni (2020) and Brooks, Cunha et al. (2022).

Border carbon mechanisms are recognised as an emerging component of market-based mechanisms to incentivise reductions in greenhouse gas emissions, with potential to influence resource recovery (Rossetto 2023a). As they are generally being designed for implementation as an add-on the emissions trading systems, border carbon mechanisms have elements of both revenue support and negative externality levy mechanisms. There has been considerable recent attention given to the sustainability of border carbon mechanisms. This is especially so where the focus is on measures that are international in nature but occur outside multilateral cooperation frameworks adopted under the UNFCCC such as the Paris Agreement.

Mehling, van Asselt et al. (2019), Leonelli (2022a) and Bellora and Fontagné (2022) had previously considered the vulnerability of border carbon measures due to the extent of their alignment with World Trade Organisation rules and conventions. Marín Durán (2023) and Overland and Sabyrbekov (2022) expanded understanding of the areas where objections may arise to include broader considerations. Identified issues included compatibility with the common but differentiated responsibilities provision under the UNFCCC and the general political reaction in other countries.

This thesis makes a significant contribution to these deliberations. The second portfolio paper, presented unique research that extends understanding of the issues needing attention. It identifies potential concerns connected to sovereignty - as well as the full range of countervailing measures that could impact smooth implementation of such international measures – that are absent in previous studies.

The paper featured the example of the coverage of intercontinental aviation within the EU emissions trading system and the subsequent preparation of countervailing measures - representing objections based on sovereignty - by 23 different third countries. It suggested this formed a potential precedent for border carbon mechanisms, particularly in reference to the CBAM proposal in the EU and the combined US/EU Global Arrangement for Sustainable Steel and Aluminium.

This result is significant in that it allows market participants, analysts and other scholars to reflect more deeply on the array of possible vulnerabilities of such programs, as well as the potential solutions. Indeed, the potential solution of global sectoral agreements put forward in the paper was supported by Mehling (2023), who cited the second portfolio paper accordingly, while noting the proven political and regulatory challenges associated with developing such sectoral agreements over the past two decades.

The second portfolio paper also made a unique contribution to the theory of corporate innovation, noting that there are inherent inconsistencies between the Porter hypothesis – which suggests higher environmental standards act as a driver of innovation by firms – and the phenomenon of carbon leakage. While other authors like Geels and Gregory (2023) aligned the modest pace of decarbonisation in emissions intensive product areas like steel to a generally declining industrial base, the second paper draws attention to the fact that carbon leakage is as legitimate a response to tighter standards as innovation.

In relation to the fourth research objective: *Assess the effectiveness of voluntary action by firms to address externalities generated within the construction and demolition waste ecosystem.*

The role that voluntary action does already – and could in future – play in incentivising increases in resource recovery has been the subject of some scholarly consideration. Much of the endeavour has focused on sustainability disclosure and the extent to which that influences, or describes the current state, of practice. Mazzucato and Ryan-Collins (2022) discussed the role that voluntary activity can take in *market-shaping*, rather than the more blunt understanding of regulatory intervention for correction of market failures.

Zharfpeykan and Akroyd (2022), after having considered the operations and reporting of listed corporations in Australia and New Zealand, noted that there were substantial differences between what companies were reporting and the operational strategies being implemented. Others like Ferlito and Faraci (2022) expressed that more sustainable business required a broader reform of business models. While voluntary action was identified as having an important role to play, the magnitude of reform was significant and required movement beyond business-as-usual practice.

This thesis provides unique and contrasting results on theories about the drivers of corporate innovation and the impact of voluntary activity of firms to improve the sustainability of operations. Portfolio paper three revealed for the first time that, while external corporate communication indicates a substantial amount regarding the activities of firms, there is more information connected to a firm's operations that is unlikely to be published in the public domain. This is because some information is strategic in nature and is designed to induce a competitive advantage. This kind of innovation may contain trade secrets; and is therefore likely to be commercial-in-confidence.

Responsive CSR will at times have a strategic element, especially for those firms participating in the capital markets where stakeholders use that information to assess the risk profiles of firms. In these cases, the absence of information to make risk areas more visible may lead to impacts on the cost of capital of firms, which in turn may impact its operating cost structure and competitiveness. In other cases, there can be a public interest in that information being made available. In these cases, mandating disclosure through regulation can likely be justified.

Customers, societal stakeholders, financiers, investors and governments can have a reasonable degree of confidence in external communication on sustainability matters by firms, though it is important that these stakeholders acknowledge such reporting has its limits. Much of the innovation taking place is strategic and designed to give firms a competitive advantage. It is natural information of this nature would be commercial in confidence and contain trade secrets; and would therefore be restricted in its external distribution.

There are opportunities resulting from this paper to reform both practice and theory. In practice, proponents of disclosure frameworks should acknowledge, in explicit terms, that firms have the right not to disclose CSR or operational sustainability information that is commercial in confidence and strategic in its nature. This would help to make the limitations of disclosures clearer and modify the expectations of those consumers of the external communications such as investors, financial services providers, stakeholders and regulators.

It is equally important, notwithstanding, to re-emphasise the impact that this kind strategic CSR can have on innovation by firms, especially in the emerging resource recovery areas of practice. This would lead to less risk of greenwashing in corporate communications. It is also important that theories of innovation be modified to take greater account of the proactive but often confidential efforts firms make to capture market opportunities.

Moving beyond theoretical understandings that tighter environmental standards or existential business threats are among the most effective motivators for *reactive* innovation, this paper illustrates the opportunity to gain competitive advantage, *strategic* in its nature, is equally influential. While the scope of this study, focused empirically on the construction and demolition waste sector in Australia and including firms connected to international markets, is globally informative, it is important that there be further research on other sectors and within other countries to validate the global applicability.

In relation to the fifth research objective: *Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management.*

Additionality is a well-understood principle for establishing the eligibility of projects and activities for different economic incentive mechanisms, from revenue to support, to cost of capital support and negative externality levies. In other words, to be eligible, a project or activity must be able to demonstrate that it is additional to business-as-usual practice.

Previous studies have highlighted though that the discipline with which additionality has been assessed varies according to a variety of factors, including the kind of support mechanism and where it is being applied. Carter, Van de Sijpe et al. (2021) found that in the area of international development assistance, quantitative rigour often gave way to systematic bias of the institutions making available the concessional resources.

Michaelowa, Hermwille et al. (2019) had noted the likely retention of quantitative financial additionality assessments under the new Article 6.4 mechanism of the Paris Agreement, notwithstanding the controversy these had created during the implementation experiences of the CDM.

Specifically connected to Australia's carbon market, Baxter and Gilligan (2017) and later MacIntosh (2022) had suggested projects, especially those that involved generating electricity from landfill gas, were not additional where they were able to generate revenues from electricity and renewable energy certificate sales. The implication of this characteristic was that projects would operate, irrespective of carbon revenues. While both the Emissions Reduction Assurance Committee (2022) and Chubb, Bennett et al. (2023) successfully rebutted these claims with the suggestion carbon revenues were indeed essential, neither provided concrete quantitative argumentation to the contrary.

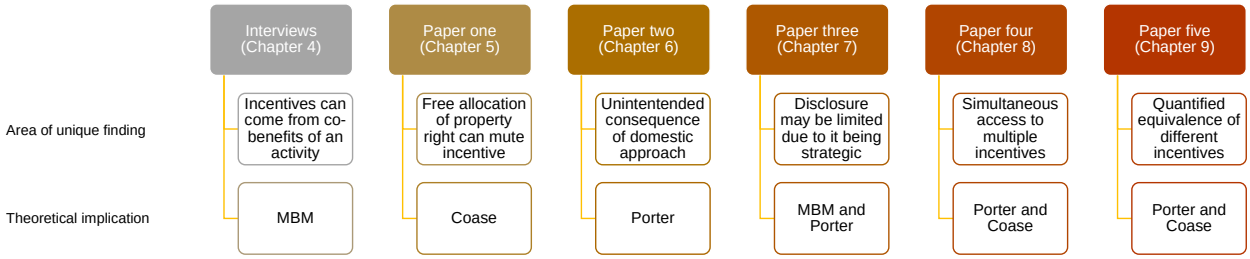
This thesis provides unique and contrasting results on these papers in the findings of portfolio paper four (Chapter 8). The paper illustrated that simultaneous access to one or more support mechanism did not necessarily invalidate a project or activity's additionality. Moreover, in some cases this is necessary to allow project proponents to manage the overall volatility in cash flows from different revenue streams. Investment decision-making within the private sector is often based on application of probability, so there is an acceptance that best-case revenue scenarios will be exposed to volatility. Carbon itself can be an important revenue stream, adding between 2-10% to the pre-tax equity return of waste-sector projects in Australia notwithstanding the existence of other revenues through the sale of electricity and renewable energy certificates. The paper also showed the importance of considering additionality at the time of the investment decision rather than on the basis of day-to-day operations, especially where the project involved the construction of long-lived infrastructure. Operational decisions, once infrastructure is built, are not as relevant to additionality.

This finding has implications for both Coase's theory and the Porter Hypothesis. It demonstrates that internalisation of a negative externality may not be enough to incentivise ongoing activity that reduces that externality. It also demonstrates that innovation may therefore require several incentives, partly to address the cost of the externality needed to compensate for its reduction and partly to manage some of the on-going risk involved the innovative activity.

10.4 Summary

This chapter, the discussion, provided an overview of results of the research undertaken specifically connected to each of the five objectives and to the research question. It also provided a comparison of the findings of the research with previous studies undertaken. The unique findings are summarised in graphical form in Figure 9 below. It illustrates a significant contribution to new knowledge in the field. Evidence of this has been shown with publications already beginning to accumulate citations by scholars around the world.

Figure 9 – Summary of the areas of unique findings of this research project



The results contain a number of implications both for connected theory as well as practice. If one considers the research question in its most basic form, it would be possible to conclude that the answers lie in subsidising – and even mandating - resource recovery and utilisation activities in the construction and demolition waste sector. This would, however, be an over-simplification of the complexity of the issues at hand. This is because there is no way of knowing that such solutions would not cause harm elsewhere. By re-allocating resources in order to incentivise one activity (in this case resource recovery), harm may be caused in other areas. This inevitably leads to movement away from the theoretical state of Pareto efficiency (refer to Section 2.3.1) and may lead to perverse incentives for firms to engage more in lobbying than innovation.

This raises questions about the extent to which efficiency is being achieved across the broader field of construction and demolition waste management, when one takes into account the policies and regulations designed to achieve outcomes in both climate change and resource recovery and utilisation. It also highlights opportunities for the future directions that policy-makers could take, exploring targeted interventions that are capable of incentivising multiple benefits or outcomes while at the same time leading to a minimisation of the regulatory compliance burden for firms.

Developing solutions in this context is challenging because, like climate change, waste management, resource recovery and recycling are globally connected problems. The negative impacts and supply chain relationships overlap political boundaries. The businesses active in the sector are regularly operating in many countries and regions and some of them are multinational corporations. Therefore, solutions designed in one jurisdiction may well resolve problems simply by shifting them to another location and creating harm elsewhere. This can be inadvertent but also, in some cases, by design. Equally, firms that operate across multiple jurisdictions will be able to identify and even exploit the regulatory arbitrages that this policy inconsistency opens up. This underscores the role for regional and multilateral cooperation. While Jakob and Mehling (2023), who cited portfolio paper two, identified the timeframes needed to finalise multilateral agreements in any area, especially global sectoral agreements, that does not mean the idea of them should be abandoned. If anything, this research highlights the need to revert to this kind of ambition. However, caution is needed to ensure design of such programs are legitimate. The EU's CBAM mechanism, which has been analysed in detail in this thesis, is an example of how legitimacy questions arise. During the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC)[3], a number of countries expressed concern over some of the mechanism's features and complained that they were not consulted during its design.

[3] Carbon Pulse. *COP28: FEATURE – Complaints over unilateral trade measures threaten progress in crucial climate talks*. Published 7 December 2023. URL https://carbon-pulse.com/242926/.

Chapter 11. Conclusion

11.1 Purpose of the chapter

This is the final chapter of the thesis. It provides a summary of the research connected to each objective connected to the topic which is: *Incentivising the recovery and utilisation of construction and demolition waste*. It is then followed by sections covering the key findings, contribution to knowledge at both the empirical and theoretical levels, recommendations for future research and then concluding remarks.

11.2 Summary of the research

This research summarised in this thesis provides important contributions to the advancement of knowledge through analysis of literature and carrying out five separate publications connected to the research question: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* The thesis is a portfolio of publications and detailed the research effort undertaken over the period 2020-23.

***Objective one**: Define the spectrum of incentives, including voluntary action, common law, subsidies, regulation, taxation and market-measures, that be deployed to incentivise resource recovery and utilisation in construction and demolition waste practices.*

This objective was achieved. It was delivered through a comprehensive literature review, followed by practitioner interviews to validate the review findings. The literature review was a comprehensive overview of books, journal articles, laws, regulations, policy documents, media reports and practice reports. It covered the main areas of relevance connected to the research question, which included construction and demolition waste, steel (as the focus area), methodologies for determining the social costs and benefits together with a description of the methods of intervention, an overview of the financial incentive mechanisms available and the theories applicable to providing incentives for business innovation and the internalisation of externalities by private firms.

Interviews with practitioners were then used as a means of validating the findings of the literature review. This assisted in establishing and then refining the focus areas of intervention that best be used to incentivise resource recovery in waste management practice.

***Objective two**: Establish the impact that climate policies can have on resource recovery and utilisation in emissions intensive industries linked to construction and demolition waste.*

This objective was achieved. It was delivered through portfolio paper one, entitled: *The Carbon Border Adjustment Mechanism: What does it mean for steel recycling?* This paper, which was published in March of 2023, presented details of longitudinal analysis undertaken to establish historical correlations between European carbon allowances, finished steel and indices for scrap steel traded ex-Turkey and ex-India – along with the application of economic logic - to establish whether it was likely the EU's newly designed CBAM program would impact steel recycling. Together the combined effect of the EU ETS and CBAM had the characteristics of both revenue support programs (where free allocations are used) and negative externality levy programs. It is also an interesting case in that the programs are regional and integrate many nations, though the CBAM component integrates countries outside the EU that were not involved in design.

The paper applied this analysis to steel emissions intensity benchmarks collected steel produced in a range of jurisdictions that are either within the EU or likely to be captured by the proposed program; and utilising either blast furnace, electric arc furnace or a combination of both. It established the likely price signal that a program such as CBAM would create, which was based around an understanding within its design that free allocation of emissions permits would be phased out. Such free allocations have the impact of muting the price signal to abate emissions in the sectors receiving them, including steel. In effect, therefore, a program whose main objective is connected to reducing greenhouse gas emissions, could have a positive impact on the incentive to recovery and recycle steel.

Objective three: *Examine the long-term feasibility of international measures – in particular border carbon measures – as a means of providing incentives for resource recovery and utilisation in construction and demolition waste practices.*

This objective was achieved. It was delivered through portfolio paper two, entitled: *The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector.* Having established (a) the potentially valuable contribution that a greenhouse gas abatement program such as the EU ETS and its CBAM adjunct program can make to incentivising resource recovery and recycling and (b) the sensitivity that such programs have to regulatory certainty, the second portfolio paper examined the long-term feasibility of border carbon mechanism programs. This included CBAM and measures under development in the US.

The paper found that there were several areas of potential vulnerability. These included the sovereignty impacts associated with the EU charging steel importers for emission resulting from production activities outside its borders and its inconsistency with the principle of common but differentiated responsibilities enshrined in the multilateral UNFCCC convention and the associated Paris Agreement.

The paper also drew parallels between border carbon mechanisms and the entry into force and subsequent repeal of the EU ETS provisions for coverage of intercontinental aviation, which may serve as a precedent for the CBAM program. This example was of particular importance because it resulted in the development and implementation of a global sectoral agreement to regulate emissions from intercontinental aviation under the auspices of the United Nations. This example showed that investments into EU ETS compliance strategy for intercontinental aviation could easily have resulted in stranded assets, highlighting the importance of regulatory stability. In this case, it became clear that there are challenges associated with inter-jurisdictional programs, especially those that are implemented unilaterally. This was an issue that had previously been considered in Section 2.1.6 of the literature review (jurisdictional complexity). In effect, therefore, interjurisdictional support mechanism programs can be more susceptible to policy risks than those in single jurisdictions, notwithstanding theoretical effectiveness.

Objective four: *Assess the effectiveness of voluntary action by firms to address externalities generated within the C&D waste ecosystem.*

This objective was achieved. It was delivered through portfolio paper three, entitled: *Relationships between sustainability disclosure, environmental innovation and performance: An examination of practice within the Australian construction and demolition waste sector*. Aside from the support mechanisms that can be implemented by individual countries, at the sub-national level or even through inter-regional or multilateral arrangements, voluntary action represents an important consideration. For voluntary action to be an effective means of addressing negative externalities, it needs to represent or be driven by an effective incentive for a change in business practice. Scholars have historically disagreed on the extent to which this occurs, with some arguing that firms are not naturally incentivised to internalise externalities and any suggestion that they are is effectively greenwashing. Others believe that firms can be naturally driven to innovate voluntarily if addressing externalities is an expectation of the marketplaces in which they operate; and there are sufficient competitors to whom a firm would lose market share without such innovation.

In the third portfolio paper, this thesis presented results of an examination of the relationship between sustainability disclosure, innovation and performance of a selection of the largest and most important operators in the Australian construction and demolition waste sector. After examining external communications and reports of these firms and through interviews, the paper noted the difference in strategic versus responsive activities within firms. The former is likely to be undertaken confidentially with a view to capturing a competitive advantage versus the latter being orientated towards satisfying the needs of customers and other stakeholders for details of how firms are addressing negative externalities.

It is therefore difficult for stakeholders to make conclusions about the effectiveness of voluntary action due to the differences in motivation for the activities, though the paper did find support for the idea that voluntary action can provide an incentive where it targets capturing competitive advantage.

Objective five: *Assess how important revenue generation mechanisms relative to the others – such cost of capital support or negative externality levies - to incentivise sustainable waste management.*

This objective was achieved. It was delivered through portfolio paper four, entitled: *The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia.* It is broadly recognised that, in some cases, market failures that give rise to externalities will require some intervention to correct. This recognises that business-as-usual is not sufficient for maximising welfare across a given society. In cases where programs that motivate private actors using economic incentives, a variety of options exist including revenue support, cost of capital support and negative externality levies. Projects and activities are nominally eligible for such mechanisms on the basis that they are additional to business-as-usual. Orthodoxy has suggested that one mechanism is enough to induce a project and that cases where they access more than one invalidates the additionality of a project; or is an indicator that it is not additional.

This thesis, through the fourth portfolio paper, considered the issue in respect of waste management (waste to energy) projects in Australia, which are eligible to access a variety of mechanisms including renewable energy certificates, cost of capital support, carbon credits and avoided costs of sending waste to landfill - in addition to electricity sales. The paper modelled the investment returns (returns on equity) based on two theoretical waste to energy projects that involved diversion of waste from landfill. The model deployed a range of sensitivities and was based on non-recourse project finance being used where debt was repaid monthly in equal amounts using a foncier repayment schedule. The research concluded that carbon finance was an important cash flow item and was able to add between 2-10% to the pre-tax equity returns across the range of sensitivities used. This cash flow item was found, therefore, to be material and its impact commensurate to other cash flow items like renewable energy certificates and electricity sales.

Accordingly, the paper provided new insight, suggesting that simultaneous access to two or more support mechanism – from revenue support to cost of capital support and negative externality levies - did not necessarily invalidate a project or activity's additionality when impacts on investment decision-making are taken into account. Moreover, access to a variety of cash flows is needed to assist with managing the inherent volatility over the life-span of an investment.

11.3 Key findings

Supported by the five portfolio papers presented herein, this thesis reveals a number of important findings relevant to the question of how to improve incentives for resource recovery and recycling with the practice of construction and demolition waste management; and the connected industries.

Firstly, motivating private actors and firms to take action to manage externalities on the basis of economic incentives involve the use of mechanisms that can be divided into three main groups: revenue support mechanisms, cost of capital support mechanisms and negative externality levy mechanisms. These classifications apply to a range of externalities and practice areas, including construction and demolition waste management. These mechanisms would generally exclude regulatory or rules-based mechanisms that either prohibit some activities or mandate others, though practitioner interviews illustrated that some regulations could impact incentives even if the links are not immediately obvious.

Secondly, there are instances where incentive mechanisms linked to greenhouse gas abatement can drive positive resource recovery outcomes. In the case of cap-and-trade programs (specifically the EU ETS and its associated CBAM mechanism), the finding was that free allocations of permits - being *de facto* property rights - had a material impact on whether this incentive became active. Providing some entities with free allocations may, inadvertently, mute the incentive to reduce emissions and, by consequence, release resource recovery as a viable abatement opportunity. This is of particular relevance to contemporary understanding of the application of Coase's Theory, which states that the initial allocation of property rights has no impact on the efficiency of the outcome. In principle and practice, supported by the findings highlighted in portfolio paper one contained in this thesis, Coase's Theory may need modification. The finding that greenhouse gas abatement programs may generate resource recovery co-benefits is of particular importance in an environment where over-regulation has been observed as a barrier to sustainable waste management practice.

Thirdly, incentive mechanisms must be stable to induce projects and activities that are additional to business-as-usual, especially in cases where the investments needed are into long-lived infrastructure assets.

There are many examples when socio-economic and political conditions change, which precipitates changes to incentive mechanisms. If these changes negatively affect prior investments, they can lead to increased risk which eventually manifests either as fewer future investments or increased premiums added to pricing. On occasions, risk premiums can negate the impact of the incentive mechanisms. Incentive mechanisms are especially sensitive when they seek to engage firms across multiple jurisdictions.

In the specific case of carbon border mechanisms, as was shown in the second portfolio paper of this thesis, the issues that emerge are complex. They can involve inconsistency and even contradictions with other programs, policies and agreements; and even impact perceptions of sovereignty in some countries that the mechanisms seek to engage. This can happen especially in cases where unilateral or plurilateral design processes are used and not multilateral. In such cases, the long-term feasibility of the mechanisms is placed at risk, which serves to undermine the potential effectiveness of those mechanisms. This also highlights the role that political boundaries of state can play in determining whether welfare is reached where interventions are implemented to correct market failures.

Fourthly, there is an important, though qualified, role for voluntary action by private firms in the pursuit of resource recovery and the reduction of negative externalities associated with waste management. While it is notable that a general degree of scepticism has emerged about the role of voluntary action (with some suggesting, in the extreme, that it amounts to greenwashing and is primarily designed to delay or avoid regulation), this is an over-simplification of the forces of self-interest that apply to corporate activity and innovation. While some voluntary activity in the domain of CSR is designed to respond to stakeholder need with disclosure of activities in which firms are engaged, there is a degree of environmental innovation undertaken by firms that is very much commercially orientated, designed to capture a competitive advantage and that remains confidential. This kind of innovation is known as strategic CSR. Through paper three, this thesis found that firms in the Australian construction and demolition waste ecosystem are engaging in both strategic and responsive CSR. Therefore, even though some of the firms are listed on stock exchanges and thereby required to disclose, the disclosures do not describe a comprehensive picture of all relevant activity.

This finding is of particular importance in the context of Porter Hypothesis, which suggests that tightening environmental standards leads to corporate innovation. Based on the findings of portfolio paper three, market preference are an equally powerful motivator for corporate environmental innovation. It is in these cases that voluntary action, driven by self-interest, can be an effective incentive for resource recovery and the minimisation of negative externalities associated with waste. Disclosure itself is not enough; and indeed, paper three found no evidence of a correlation between reporting and firm performance.

Finally, paper four found that simultaneous access to two or more support mechanisms did not necessarily invalidate a project or activity's additionality. Investment decision-making, especially into infrastructure, is generally based on uncertainty and probability. Whether or not a project goes ahead or not is, therefore, generally based on assumptions about the likelihood of cash flows and costs arising over long time horizons when many things can change. In order to encourage positive decisions, firms must assess the returns on equity based on probability weighted sensitivities. Contrary to what a lot of scholars and analysts have found over many years, this paper – having looked specifically at sustainable waste to energy projects in the Australian carbon market - identified that access to a spread of cash flows is helpful for managing inherent volatility over the lifespan of an investment. This has implications for policy makers and managers not just in Australia but also throughout the world. It suggests that simultaneous access to support mechanisms is not only an invalid reason to conclude a project or activity is not additional business-as-usual, but also rather an essential ingredient in prudent investment activity.

11.4 Ex-post response to the research question

This thesis began with the research question: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* In the introduction, five distinct research objectives were formulated. Each objective was addressed individually, with objective one using the literature review and practitioner interviews and objectives two to five addressed via portfolio papers one to four.

The ex-post response is complex and depends on context, though there are important roles for revenue support, cost-of capital support and negative externality levies. There are also instances in which voluntary action can be effective, though the existence of strategic CSR may limit the extent to which the benefits are communicated broadly. Inducing innovation at the firm level requires that incentives be robust and durable. Without this, firms will lose confidence in them and this will impact the extent to which changes in practice or investment in innovation will result.

11.5 Contribution to the body of knowledge

This research project has put forward several important theoretical and empirical contributions to knowledge in the fields of waste management, welfare economics, corporate innovation, climate change and international trade (constrained by environmental considerations). There are also implications for policy development. These contributions are described in the following sections.

11.5.1 Empirical

At its core, promoting improvements in waste management practice through incentivising resource recovery is about having an empirical impact. It is about laying down the guideposts to that can lead to improvements in practice.

Construction and demolition waste management is among the most important areas where this research contributes new knowledge. This is particularly so in the finding, as shown in the first portfolio paper, that climate-orientated action can deliver resource recovery co-benefits. This is particularly relevant due to the previous findings of Shooshtarian et al (2022) and others that over-regulation represented a barrier to more sustainable construction and demolition waste management practice. There are some preconditions around the extent to which co-benefits can be delivered, such as the need to reduce to the maximum extent possible free allocation of emissions allowances. This will ensure that abatement price signals reach the maximum number of measures including those that involve recovering and utilising waste that would otherwise be directed to landfill. By leveraging climate action, managers will be able to focus activities to achieve the most efficient outcomes. Policy makers will be able to rationalise the number of endeavours that will lead to less regulatory burden for enterprises whose activities they seek to influence.

There are important contributions to climate policy. The second portfolio paper illustrates that the sustainability of unilaterally designed international mechanisms – like border carbon mechanisms – are at risk due to their inconsistency with the *common but differentiated responsibilities* provision of the UNFCCC and the perceptions in other countries of sovereign autonomy. This goes beyond considerations of consistency with WTO trade rules, which had been the main focus of scholarly work. It also places into frame the tension between the need to remove free allocation of permits in emissions trading systems (which are understood to be limiting incentives to abate) and the problem of carbon leakage. This occurs in an environment where more rapid movement toward decarbonisation is held as a priority almost universally as enshrined in the Paris Agreement. The second portfolio paper draws similarities between border carbon mechanisms and the experiences of covering intercontinental aviation within the EU ETS, for which the solution became removal of these activities from the system and replacement with a global sectoral agreement in the form of the CORSIA mechanism.

The thesis, through the third portfolio paper, contributes knowledge in the area of welfare economics. While the research project was designed around the practice area of resource recovery in construction and demolition waste – and the specific product area of steel – its findings are relevant to many areas where economic incentives can be used to address environmental externalities.

One of the key contributions is to the broad understanding of what constitutes additionality and how it can be assessed, with the insight revealed that a project or activity can access two or more support mechanisms and still be additional. As the research has shown, this can also be a desirable characteristic that would encourage more investment because the diversity of cash flow provides a natural hedge against volatility. The impact of this work is immediately relevant to countries seeking to formalise the new Article 6.4 mechanism of the Paris Agreement, while at the same time develop national policies to further implementation of NDC targets. It is also of relevance to broader spheres of finance (development finance, climate finance and sustainable finance), where there has been a perception that if a project is accessing carbon markets then it should not be eligible for climate or development finance and vice versa.

The area of sustainable finance is of particular relevance. As had been discussed in Section 2.4.7 of the literature review, regulators have sought to simplify definitions of what is a sustainable investment through the introduction of taxonometric approaches. This allows different investment products to be labelled sustainable if, for example, they illustrate that there is an impact in respect of climate change mitigation, advancement of the circular economy or amelioration of atmospheric pollution - all of which may be consequences of sustainable construction and demolition waste management practices that lead to avoidance of landfilling. However, the simplification process may result in capital allocations to projects and activities that would have happened anyway. In such cases, the investments are not additional, yet they are formally labelled as sustainable, while in parallel the broader area of sustainable finance fights to defend itself from greenwashing claims. This research provides cause for capital market participants and regulators to reflect on the issue of additionality. While it is not a simple concept to assess, the enhanced understanding of what kinds of incentive mechanisms and combinations thereof contribute to projects and activities that are additional to business-as-usual will, at a minimum, provide cause for consideration by the broader sustainable finance community.

11.5.2 Theoretical

The thesis makes a number of important theoretical contributions. As mentioned in earlier sections, the research endeavour afforded an opportunity to carry out both deductive research (to determine the applicability of existing theories) as well as inductive research (to develop new theories).

From a deductive perspective, this research project first tested the applicability of Coase's Theory, which stems from the broader discipline of welfare economics. Among the main propositions within Coase's Theory is that social costs (externalities) are best internalised through the use of property rights-based systems. Coase also held that, where transaction costs are assumed to be zero, the initial allocation of property rights would make no difference to the social cost or efficiency of the outcome. This research has illustrated that, in the context of emissions trading systems, it is material whether or not emissions permits are first allocated to liable entities.

While free allocation occurs generally as a means of reducing the risks of carbon leakage, it is not plausible to state that this can be written off as a transaction cost. Liable entities being in possession of freely allocated rights to emit reduces the incentive to abate. This principle was elaborated in detail within the first portfolio paper. It would suggest further qualifications are needed, as an update to Coase, to the extent that one maintained the theory were valid.

Following on from this, the Porter Hypothesis suggests that corporate innovation will take place in response to higher environmental standards. However, this theory appears to be imperfect on several counts. The second portfolio paper of this thesis illustrates that the Porter Hypothesis, if it held true, ought to invalidate concerns about carbon leakage. Firms, when faced with higher emissions standards, would innovate rather than relocate. This seems to overlook the role that imports have in replacing higher cost production. Indeed, portfolio paper two presented evidence that suggests, over the last 10 years, the European Union has gone from being a net exporter of steel to an importer of growing volume. All of this occurred while emissions constraints became tighter and European carbon prices increased. As in the case of Coase's Theory, this would suggest further qualifications are needed, to the extent that one maintained the hypothesis were valid.

From an inductive perspective, these contributions open the way to the development of either (a) adaptations or qualifications of these theories, or (b) the development of altogether new theories.

11.5.3 Policy implications

Policy makers have the task of identifying and rectifying market failures. This thesis provided a detailed overview of the different kinds of economic incentive mechanisms that can be used, from revenue support to cost-of-capital support and negative externality levies. Any interventions that result in the provision of incentives ought to, in principle, result it the most efficient (Pareto or Kaldor-Hicks) outcome. This would imply that those harmed by negative externalities or those producing positive externalities are compensated as directly as possible. In complex economic and social environments and where cross-border impacts are involved, that may not always be possible. It can, however, be an objective.

The opportunity exists for policymakers to reduce regulatory burden for firms by leveraging voluntary action and co-benefits wherever possible. This, if achieved, would likely serve to reduce overall transaction costs and lead to optimised efficiency.

11.6 Recommendations for further research

The research undertaken as part of this thesis is subject to some important limitations: Firstly, there are many different materials used in construction and equally different feedstocks used in their production. In order to focus the research, it considers steel in great detail. While steel is an important construction material and worthy of detailed consideration, it there are potential differences with others like aluminium, plasterboard, cement, among others, which this research does not cover. Secondly, it is focused on economic incentives as the motivators for change. There are other kinds of incentives, which include regulatory actions to prohibit certain actions or to mandate others, as well as other factors that affect decision-making such as ethics. Thirdly, it does not analyse the forces that bring about the incentives via public intervention in markets, which might be explainable using theories of the political economy and public choice. These were outside the scope of this research project and could not be covered, though they serve as a basis for identifying areas for further research.

Accordingly, there are three main areas in which further research can be directed following publication of this thesis. The first is linked to the theoretical contribution aforementioned. Neither Porter nor Coase would have been able to review most recent experience with greenhouse gas emissions trading systems, which now make up an emerging and important area in which market-based incentives are being deployed to induce positive climate externalities across the world. Adaptations or qualifications to these theories, or development of altogether new theories, are priority areas for theoretical research emerging from this research endeavour.

Secondly, while much research had been undertaken in the 2000-10 period on global sectoral agreements to deal with climate change, contemporary understanding of carbon leakage suggests this research endeavour needs further attention. Jurisdictions with emissions trading systems are compelled to use free allocation systems to provide protection against carbon leakage, which is especially relevant in a global environment where different countries are moving (acceptably) at different paces on mitigation due to common but differentiated responsibilities.

At the same time, the imperative to reduce emissions grows and it is clear that free allocation policies mute the incentive to abate. This research has shown that to be the case in the area of steel. Therefore, in parallel to the work being done to consider border carbon mechanisms – which have their own vulnerabilities – further research is needed to explore contemporary issues in the design of multilateral sectoral mechanisms that create incentives for hard-to-abate industries such as steel.

The final area for further research is that of sustainable finance. Safeguarding against concerns about greenwashing depends on greater attention being paid to the additionality of the underlying projects and activities populating investment products. There is a tension here, as the capital markets have demanded simplicity and additionality is an inherently complex characteristic to evaluate. This becomes even more complex when a lot of sustainable investment products are funds that invest in firms rather than projects or activities. Notwithstanding, this emerges as a priority area for research, as demand for solutions to bolster the creditability of sustainable finance, while at the same time drive incentives for changes to more sustainable practices, including but not limited to resource recovery linked to construction and demolition waste, is increasing with the passing of each day.

11.7 Concluding remarks

This research project began by asking the question: *How can incentives for resource recovery and utilisation in construction and demolition waste be improved?* It isolated steel – in particular where scrap steel can be used as an alternate feedstock for new steel production over raw materials like iron ore and metallurgical coal - as a material of principle interest.

Through a portfolio of separate but linked research papers, it demonstrated deeper understanding of how economic incentives can be applied effectively. This is connected not just to the design of support programs - such as revenue support, cost of capital support and negative externality levies - but also eligibility for them. It also provided insight into the risks of designing programs that become targets for countervailing measures, undermining the credibility of incentives they are designed to generate.

The research also showed the important role that voluntary action can play where it is designed to confer competitive advantage to firms. The limitation on voluntary action is that not all marketplaces have access to information that allows preferences for products, materials and services to be comprehensively applied. Voluntary action, where it is actively communicated externally by firms, can draw unwanted criticism of greenwashing, though the research showed that a degree of voluntary effort is strategic in nature and firms may wish to retain it confidentially; and treated as trade secret.

Finally, construction and demolition waste, like many other areas of practice, is linked to both national and international forces in an interconnected world. Therefore, it is difficult to separate the incentives from those that are purely operating at the national level with those that have a multilateral impact. In this respect, international coordination, if not full collaboration, is desirable to prevent trade friction, inefficient allocation of resources and the continuation of otherwise avoidable negative externalities.

Appendix A – Ethics approval

RESEARCH SERVICES
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
THE UNIVERSITY OF ADELAIDE

LEVEL 4, RUNDLE MALL PLAZA
50 RUNDLE MALL
ADELAIDE SA 5000 AUSTRALIA

TELEPHONE +61 8 8313 5137
FACSIMILE +61 8 8313 3700
EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

Our reference 35101

12 May 2021

Professor Jian Zuo
School of Architecture & Built Environment

Dear Professor Zuo

ETHICS APPROVAL No: H-2021-069
PROJECT TITLE: Incentives for future trading of construction and demolition waste

The ethics application for the above project has been reviewed by the Executive, Human Research Ethics Committee and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research 2007 (Updated 2018)* involving no more than low risk for research participants.

You are authorised to commence your research on: 12/05/2021
The ethics expiry date for this project is: 31/05/2024

NAMED INVESTIGATORS:

Chief Investigator:	Professor Jian Zuo
Student - Postgraduate Doctorate by Research (PhD):	Mr Daniel Marc Rossetto
Associate Investigator:	Professor George Zillante

CONDITIONS OF APPROVAL: Thank you for addressing the feedback. The revised ethics application provided on the 10th of May 2021 has been approved.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled Annual Report on Project Status is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/research-services/oreci/human/reporting/. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the information sheet and the signed consent form to retain. It is also a condition of approval that you immediately report anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol or project investigators; and
- the project is discontinued before the expected date of completion.

Yours sincerely,

Professor Paul Delfabbro
Convenor

The University of Adelaide

Appendix B – Summary of interviews

This appendix contains the main proceedings and minutes of the practitioner interviews, supporting the contents of Chapter 4.

Relating to voluntary action

Voluntary action is, in effect, the scenario most aligned to the Market-Based Management theory. It represents the situation in which markets have the least amount of intervention and suppliers of products and services are driven by consumer preferences. The marketplace therefore offers incentives to supply products and services at levels of quality, quantities and prices that meet those consumer preferences. Feedback from interview participants that related to voluntary action is summarised below:

Interviewee 01 - The interview noted that the firm's involvement in the scrap steel market is on a purely voluntary basis. Most of its business is done with entities that are also acting on the basis of self-interest (or voluntarily). It is possible to transact twice. This arises from earning gate fees for scrap metal and waste being disposed. Then, the organisation is able to charge customers who seek to procure the scrap steel. This indicates the potential existence of an information asymmetry. That is, organisations that need to dispose of scrap metal may not be aware of the real demand that exists for this kind of waste. Were they aware of such demand, they might be less willing to pay for disposal.

Interviewee 02 - The interviewee referred to Extended Producer Responsibility (EPR) schemes as a possible means for achieving greener steel production. Such schemes involve making suppliers of products responsible – or liable – for their product at the end of its useful life. In effect, such a scheme implies that a producer of a product like steel would be responsible for its collection and disposal at the end of the product's useful life. If it were a legal obligation, one could describe such a scheme as creating a liability for the producer.

The interview participant felt like these schemes might hold some potential for green steel, though there is uncertainty about how best they could be applied. Some examples from other products were cited in the interview such as carpets and lighting, which could be used as reference points. It was noted that in both carpets and lighting, there was evidence that these began as voluntary initiatives by producers that had sensed a preference emerging among their customers. In that sense, it may not be essential to create regulatory liabilities to ensure EPR schemes evolve. There are, however, many differences between products like carpets and lighting when compared to steel, which need to be better understood before any definitive conclusions could be drawn. It was also noted that leasing of green steel might be a voluntary alternative to the need for other regulatory means of revealing a liability.

Notwithstanding, given no such schemes are yet mainstream in the Australian steel industry, it is unlikely – at least at present – that the voluntary forces of self-interest are sufficient to drive the introduction of EPR schemes when it comes to steel products. The interview participant also made reference to the Materials and Embodied Carbon Leadership Alliance as an important and relatively new initiative designed primarily to signal demand for sustainable, responsible and green from the end user or downstream market perspective.

Interviewee 03 - The participant referred to the fact that regionally specific endowments and attributes, such as having access to iron ore (magnetite) and renewable energy resources, ought to be considered important factors in delivering green steel. The participant mentioned that the internal perception within the company that greening of steel production is a broader community expectation. There is a point in the future where all stakeholders, customers and regulators might simply expect that steel become greener over time. Therefore, the ability of steel producers to be able to satisfy customer need over time, on a purely voluntary basis, will depend on the organisation's technical ability to produce steel with demonstrably lower levels of environmental impact while at the same time finding a means to deal with any extra cost involved in doing so. There is currently a high degree of uncertainty affecting the decision making of private sector actors. The participant made mention that future expectations of market conditions, including competitive positioning, are important parameters affecting investment decision-making - which is over long cycles.

Relating to taxation and subsidy

Taxation and subsidy programs arise in situations where policy makers seek to utilise the forces of price equilibrium to dissuade consumption of products and services that generate negative externalities by taxing them or encourage those activities that generate positive externalities, by subsidising them. The effects of taxation and subsidy programs, from a theoretical perspective, were described in Figure 5 and Figure 6 in Section 2.4.2.

Interviewee 04 - The participant noted that there are inconsistencies between states when it comes to general waste management and disposal practices and charges. Where the costs of disposal are significantly high in one state, it can help to build a case for disposal into another jurisdiction. This would occur if the travel costs plus disposal costs in the other jurisdiction is less than the disposal cost in the original location.

The nature of the cost differentials, which can be considered arbitrages, are illustrated in Figure 3 within Section 2.1.3. The existence of these arbitrages implies that self-interested actors, where they have access to all relevant information, can and will seek to exploit them on the basis of economic advantage. The participant suggested that states harmonise rules to avoid such arbitrages. This supports the notion that there are cross-border impacts from different, regionalised approaches where the feedstock and commodities are tradable across those boundaries. Therefore, the question of common interest cannot really be answered without taking this into account. It raises a subsequent issue about the hypothecation of revenues collected from landfill charges.

Green Industries SA is a state agency established to promote the circular economy. It is funded, under the Green Industries South Australia Act 2004, through appropriations from landfill waste collection charges and then allocates funds to private and public sector actors seeking to develop innovative technologies and projects that tackle waste. This is not compensatory at an individual level, though could be considered more broadly to be so if the entire state were considered the party being harmed by landfill.

Interviewee 05 - The interviewee mentioned that the organisation has a scoring system in place that could allow more expensive items - in capital cost terms - to be purchased if they offer life cycle cost savings. While this is a general point, it may relate to steel and shows evidence of how two parties might voluntarily find a way to transact independent of any other laws or regulations.

Interviewee 06 - Under Section 90 of the Australian Constitution, the states and territories cannot impose a tax/excise on production. They can however, charge fees and levies for environmental externalities. Licence fees for industry under South Australia's Environment Protection Act 1993 are closely linked to emissions of pollutants, while levies on solid and liquid waste disposed of at depots are subject to levies.

Relating to regulation

Regulation is common within the Australian construction and demolition waste ecosystem. In principle, there are broad guidelines for public policy makers in Australia that suggest regulation be used, in general, when the transaction costs of different solutions are prohibitive (Council of Australian Governments 2007). In such cases, regulations that either prohibit certain practices or mandate others are deployed. In some cases, the existence of regulations in other areas create spill-over effects that incentivise resource recovery.

Interviewee 02 - The interview participant suggested that Building Code of Australia (BCA) reform – being rules that govern minimum standards that apply to construction in Australia - could be used to accelerate the uptake of low embodied carbon materials. An observation stemming from this is that BCA provisions effectively signify involuntary transactions, where measures are deemed to satisfy as opposed to performance based. During discussion with the participant and through follow up correspondence – taking place during the process of finalising the minutes, it was noted that the cost of compliance with domestic regulations may in fact be a driver for the export of scrap steel. This suggests that regulation in Australia might inadvertently be creating a situation whereby local producers less able to secure supplies of scrap competitively versus export businesses. This leads to an observation that statutes and regulations may sometimes inhibit efficiency.

Interviewee 03 - It was noted in the interview that technology costs are high for quite a lot of the approaches being considered by market participants to achieve green steel. The participant also noted that current and future regulatory requirements are very much part of the set of drivers that influence the plans of incumbent steel producers. The observation here is that future regulation may in fact reveal some kind of liability for negative externalities, which becomes then an incentive to act now to avoid that liability. In other words, it is possible that a future liability is enough to stimulate change. While this might be partially true, it can be considered alongside a desire to not fall too far behind competition in the event that there is a technological breakthrough.

Interviewee 04 - The participant spent some time discussing the merits of a polluter pays system, suggesting that the absence of such a system in Australia across the board is likely to be evidence of a market failure in this area. Liabilities for many of the negative externalities associated with steelmaking have not really been revealed yet in regulation. The participant felt that the incentive for a polluter to pay for a solution ought to be linked to a revealed right or liability. The participant then suggested an EU-style Environmental Liability Directive would be helpful, which creates a regulatory liability for ecological damage. A suggestion was also provided that there ought to be a mechanism to allow for the ex-post enforcement of long-term commitments that developers often make in order to secure planning approval for their project. In this respect, a commitment to do something in order to obtain approval could become regarded as a liability. Some time was spent discussing the potential merits of creating a system for the transfer of liability in eventual product stewardship schemes that might be applied to green steel. This might be considered helpful in the context of the long-term solvency risk of the entity taking on the liability.

This might be useful in situations in which the entity holding the liability defaults, where the traditional practice is that the liability would transfer back to the public via the state. This participant felt as though there was not enough agreement on what green steel is, what standards should apply and how it should be determined. If there were to be any efforts to regulate green steel, such definitions would become essential.

For example, recycling steel within a manufacturing process ought to be clarified. The participant felt that the lack of definitions and standards was leading to confusion in other areas of the market. Many steel producers claim that steel waste captured during the initial manufacturing process is part of the recycled content, which is not commonly agreed across the broader market. This matter, therefore, ought to be clarified. Clarity over definitions and standards would most likely come through regulation, though there is an open question about which jurisdiction's regulation would have the most legitimacy at the global level.

Interviewee 05 - The participant referred to extended producer responsibility (EPR) schemes as a future direction for client organisations, such as the one the participant represents, would seek to develop. Consistent with the observations made with other participants though, exactly how and where EPR would be applied in the context of green steel is not well understood across industry. The participant also felt that there was a degree of plausibility in proposals to use regulatory measures to increase demand downstream - with the example being for star ratings – though this begins to muddy the waters with regard to other mandatory systems such as the Building Code of Australia.

Relating to common law

While the most obvious regulations that apply to construction and demolition waste activity in Australia are derived via deliberate action by lawmaking bodies like the parliaments at state and national level, common law also provides a degree of impact on the incentives relating to certain activities.

Interviewee 06 - Common law was mentioned on a number of occasions. The participant acknowledged that, while a number of legal cases were relevant to the site contamination framework and taken into consideration, there was no cause and effect. The need for a framework had been recognised long before the cases had been noted, according to the participant. That is, the existence of these cases did not influence the development of new site contamination provisions despite the fact that people like Posner claim that regulation should be used fill in gaps in the common law. Within the Fact Sheet, mention is made of the unnecessary costs, delays and disputes arising as a result of unrevealed rights and liabilities following the use of "*optional planning mechanisms to deal with site contamination*".

There was reference to common law disputes implying that some disagreements may need to be escalated to the courts for clarifications using provisions under common law, largely because the optional mechanisms discussed earlier are insufficient. Within the RIS, reference is made to the fact that, in response to Planning Advisory Notice, developers had previously argued successfully in court that a consultancy report was sufficient to establish whether there is contamination on a change in use planning application site and therefore no site contamination audits were needed (page 14). This is, in effect, an observation of where policy makers have considered common law insufficient for its purpose and actively sought to override those provisions by introducing regulatory requirements.

Relating to market-based programs

Construction and demolition waste affords some opportunity to harness market forces through the deployment of market-based programs. Other programs, particularly those linked to the positive externality of reduction of greenhouse gas emissions, can also impact the level of resource recovery occurring across the construction and demolition and other sectors.

Interviewee 02 - Externalities were discussed in the context of measurement, verification and certification of Sustainable Development Goals (SDG) as attributes of green steel. In effect, SDG benefits could be regarded as positive environmental and social externalities. If they had legal characteristics that allowed them to be purchased and/or sold separately, this might help to create a revenue stream beyond solely steel sales that might support capital allocation within the green steel market; like one might see in the market for green electricity where the environmental attributes can be separated from the basic commodity. However, it was noted that this is a very under-developed area and would require significant time, effort, thought and consultation to advance. This led to a general observation that market failures being observed in scrap steel, which have not yet been particularly well quantified, seem to be a big limit to better and more efficient utilisation of scrap. The need to have protection for Australian producers from import competition was highlighted as a possible safeguard against cross-border impacts of new policy measures.

Interviewee 03 - The participant noted in the interview that there might be some advantages for regulatory mandating of demand for green steel. Considering the example of renewable energy that has benefited from a strong long-term demand signal in many jurisdictions that has allowed it to reduce its unit costs through economies of scale, the same might be possible in green steel. However, some of the changes needed to allow more greening of steel production require significant lead times to achieve.

Therefore, even with some regulatory demand signalling that might arise in the future, self-interested companies could probably not afford to defer consideration of these alternatives until regulatory action were proposed. This introduces an observation that in something as potentially capital intensive as green steel production, the risks of being regulated before one is ready are significant.

This might therefore be as important a driver towards alignment with common interest as many of the previously mentioned factors. The proposal by the European Union in early 2020 to introduce a carbon border adjustment measure (CBAM) is gaining popular focus within the industry even beyond those who trade specifically in and with the European Union. In respect of greenhouse gas emissions, these represent a potential way of internalising externalities downstream at the point of market entry. The observation here is that CBAM is almost certainly not the most efficient solution given that the revenues collected at the border would not be used to fund compensation of those most harmed by an issue such as climate change. Therefore, just because a CBAM is introduced and arguably there might be an extended reach of programs that drive the internalisation of a climate externality, the distorted welfare impacts do not necessarily guarantee that society will be better off as a consequence. The steel industry is also carefully evaluating the nature, implementation schedule and impacts of the CBAM measures currently under consideration around the world.

Interviewee 04 - The participant referred to the fact that finding solutions can often require more time for design or technical consultants. The observed experience within projects is that clients, where acting on a purely voluntary and self-interested basis, are more often than not unwilling to fund this extra work. The only situations that might likely lead to an alteration of this observed phenomenon are (a) where there is a clear pathway to a new cash flow that might come from the extra investigation and work, or (b) if there were a future regulatory liability or perhaps even a contingent liability that might arise from not carrying out further exploration.

Interviewee 05 - The participant made mention of the experience that design consultants, when preparing technical specifications and designs, are generally conservative. This means that they might be resistant to change, even if the client were pushing for a particular kind of solution. In these cases, even if there were an alternative with recycled content, they may overlook the solution due to uncertainty over the performance. As an observation, this could be as much to do with the means of procurement of the design consultants. For example, was the need for innovation made clear in the specification or tender documents from which the client organisation made its engagement decision? This is quite an important factor, because the resistance might be there based on the fact that a more brief scope of work was the basis for pricing the project in the first place.

References

Aboulamer, A., K. Soufani and M. Esposito (2020). "Financing the circular economic model." Thunderbird International Business Review.

Agamuthu, P., K. M. Khidzir and F. S. Hamid (2009). "Drivers of sustainable waste management in Asia." Waste management & research **27**(7): 625-633.

Agoraki, M.-E. K., M. Giaka, D. Konstantios and V. Patsika (2023). "Firms' sustainability, financial performance, and regulatory dynamics: Evidence from European firms." Journal of international money and finance **131**: 102785.

Alemanno, A. (2013). Is There a Role for Cost-Benefit Analysis beyond the Nation-State? Lessons from International Regulatory Cooperation, Oxford University Press.

Ali, A., D. J. Kelley and J. Levie (2020). "Market-driven entrepreneurship and institutions." Journal of business research **113**: 117-128.

Allwood, J. M. (2014). Chapter 30 - Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies, Elsevier Inc.

Amighini, A., P. Giudici and J. Ruet (2022). "Green finance: An empirical analysis of the Green Climate Fund portfolio structure." Journal of cleaner production **350**: 131383.

Andersen, J. G. (2012). Welfare States and Welfare State Theory. CCWS Working Paper. Denmark, Centre for Comparative Welfare Studies, Institut for Økonomi, Politik og Forvaltning, Aalborg Universitet.

Aranda-Usón, A., P.-T. Pilar, M.-V. Luz María and S. Sabina (2019). "Financial Resources for the Circular Economy: A Perspective from Businesses." Sustainability (Basel, Switzerland) **11**(3): 888.

Armat, M. R., A. Assarroudi, M. Rad, H. Sharifi and A. Heydari (2018). "Inductive and Deductive: Ambiguous Labels in Qualitative Content Analysis." Qualitative report **23**(1): 219-221.

Asare, W., S. Oduro–Kwarteng, E. A. Donkor and M. A. D. Rockson (2022). "Cost-effectiveness of incentive schemes for waste material resource recovery." Cleaner Waste Systems **2**: 100019.

Asare, W., S. Oduro Kwarteng, E. A. Donkor and M. A. D. Rockson (2020). "Recovery of Municipal Solid Waste Recyclables under Different Incentive Schemes in Tamale, Ghana." Sustainability (Basel, Switzerland) **12**(23): 9869.

Australian Building Codes Board (2011). National Construction Code. NCC Australian Building Codes Board. Canberra, ABCB.

Australian Bureau of Statistics (2013). Waste Account, Australia, Experimental Estimates. A. B. o. Statistics. Canberra, Australian Government Publishing Service.

Australian Bureau of Statistics (2013). The Waste Management Industry in Australia. National Waste Reporting 2013. Canberra, Department of Agriculture, Water and the Environment.

Australian Competition and Consumer Commission. (2020). "What is the market?" Australian Competition and Consumer Commission Retrieved 16 May 2021, from https://www.accc.gov.au/business/anti-competitive-behaviour/anti-competitive-conduct#what-is-the-market-.

Australian Government (2023). Safeguard mechanism reforms: Position paper. Department of Climate Change Energy the Environment and Water. Canberra, Commonwealth of Australia.

Ayar Şentürk, H. and K. T. Özkan (2023). "The relationships among the logic of value innovation, strategic decisions and market-driven factors." The Journal of business & industrial marketing.

Baker, J., B. (2007). "Market Definition: An Analytical Overview." Antitrust law journal **74**(1): 129-173.

Barrett, J., G. Peters, T. Wiedmann, K. Scott, M. Lenzen, K. Roelich and C. Le Quéré (2013). "Consumption-based GHG emission accounting: a UK case study." Climate policy **13**(4): 451-470.

Bartlett, J. (2019). Reducing Risk in Merchant Wind and Solar Projects through Financial Hedges. Washington DC, Resources for the Future.

Baxter, T. and G. Gilligan (2017). "Verification and Australia's emissions reduction fund: Integrity undermined through the landfill gas method?" Australian journal of environmental law **4**(Jun 2017): 1-29.

Bellora, C. and L. Fontagné (2022). EU in Search of a WTO-Compatible Carbon Border Adjustment Mechanism. Paris, Centre d'Etudes Prospectives et d'Informations Internationales (CEPII).

Benachio, G. L. F., M. d. C. D. Freitas and S. F. Tavares (2020). "Circular economy in the construction industry: A systematic literature review." Journal of cleaner production **260**: 121046.

Bendor, R., E. Eriksson and D. Pargman (2021). "Looking backward to the future: On past-facing approaches to futuring." Futures : the journal of policy, planning and futures studies **125**: 102666.

Bernard, H. R. (2018). Research methods in anthropology : qualitative and quantitative approaches. Lanham, Maryland, Rowman & Littlefield.

Blomsma, F. and G. Brennan (2017). "The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity." Journal of Industrial Ecology **21**(3): 603-614.

Boomsma, T. K. and K. Linnerud (2015). "Market and policy risk under different renewable electricity support schemes." Energy (Oxford) **89**: 435-448.

Boute, A. (2020). "Regulatory stability and renewable energy investment: The case of Kazakhstan." Renewable & sustainable energy reviews **121**: 109673.

Broadbent, C. (2016). "Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy." The International Journal of Life Cycle Assessment **21**(11): 1658-1665.

Brooks, S. M., R. Cunha and L. Mosley (2022). "Sovereign Risk and Government Change: Elections, Ideology and Experience." Comparative political studies **55**(9): 1501-1538.

Brown, J. (2018). "Environmental economics." **Encyclopaedia Brittanica**.

Buchanan, J. M. (1969). "External Diseconomies, Corrective Taxes, and Market Structure." The American economic review **59**(1): 174-177.

Calabresi, G. (1968). "Transaction Costs, Resource Allocation and Liability Rules - A Comment." The Journal of law & economics **11**(1): 67-73.

Calabresi, G. (1991). "The Pointlessness of Pareto: Carrying Coase Further." The Yale law journal **100**(5): 1211-1237.

Caldecott, B. (2022). "Climate risk management (CRM) and how it relates to achieving alignment with climate outcomes (ACO)." Journal of sustainable finance & investment **12**(4): 1167-1170.

Caldera, S., T. Ryley and N. Zatyko (2020). "Enablers and Barriers for Creating a Marketplace for Construction and Demolition Waste: A Systematic Literature Review." Sustainability (Basel, Switzerland) **12**(23): 9931.

Calvet, L., G. Gianfrate and R. Uppal (2022). "The finance of climate change." Journal of corporate finance (Amsterdam, Netherlands) **73**: 102162.

Calvo, N., L. Varela-Candamio and I. Novo-Corti (2014). "A Dynamic Model for Construction and Demolition (C&D) Waste Management in Spain: Driving Policies Based on Economic Incentives and Tax Penalties." Sustainability (Basel, Switzerland) **6**(1): 416-435.

Carmichael, D. G., K. A. Lea and M. C. A. Balatbat (2016). "financial additionality and viability of CDM projects allowing for uncertainty." Environment, development and sustainability **18**(1): 129-141.

Carter, P., N. Van de Sijpe and R. Calel (2021). "The elusive quest for additionality." World development **141**: 105393.

CDM Executive Board (2012). Methodological tool: Tool for the demonstration and assessment of additionality. Bonn, UNFCCC. **Tool 01 (version 07.0.0)**.

CDM Policy Dialogue (2012). Climate change, carbon markets and the CDM: A call to action. CDM Policy Dialogue. Bonn, UNFCCC.

Centobelli, P., R. Cerchione, D. Chiaroni, P. Del Vecchio and A. Urbinati (2020). "Designing business models in circular economy: A systematic literature review and research agenda." Business Strategy and the Environment **29**(4): 1734-1749.

Chen, J. (2020). "Industrial Organisation Definition." Investopedia Retrieved 19 April 2022, from https://www.investopedia.com/terms/i/industrial-organization.asp#:~:text=Industrial%20organization%20is%20a%20field,theory%20of%20price%20to%20industries.

Chubb, I., A. Bennett, A. Gorring and S. Hatfield-Dodds (2023). Independent Review of Australian Carbon Credit Units: final report. D. o. C. C. E. t. E. a. Water. Canberra, Australian Government Publishing Service.

Clean Energy Finance Corporation and Arup (2021). Energising resource recovery: the Australian opportunity. Investment Outlook. Sydney, Australia, Clean Energy Finance Corporation.

Cleveland, M., J. I. Rojas-Méndez, M. Laroche and N. Papadopoulos (2016). "Identity, culture, dispositions and behavior: A cross-national examination of globalization and culture change." Journal of business research **69**(3): 1090-1102.

Coase, R. H. (1960). "The problem of social cost." The Journal of Law and Economics **56**(4): 837-877.

Coase, R. H. (1988). The firm, the market and the law. Chicago & London, The University of Chicago Press.

Cooper, D. R., N. A. Ryan, K. Syndergaard and Y. Zhu (2020). "The potential for material circularity and independence in the U.S. steel sector." Journal of industrial ecology **24**(4): 748-762.

Coulson-Thomas, C. (2014). "Can we alter behaviours without “culture change”?" Strategic direction (Bradford, England) **30**(5): 37-39.

Council of Australian Governments (2007). Best Practice Regulation: A Guide for Ministerial Councils and National Standard Setting Bodies. D. o. P. M. a. Cabinet. Canberra, Australian Government Publishing Service.

Council of Australian Governments (2020). Phasing Out Waste Exports Response Strategy. Canberra, Council of Australian Governments.

Cousins, M. (2005). European Welfare States: Comparative Perspectives. London, SAGE Publications.

Crompton, P. (2015). "Explaining variation in steel consumption in the OECD." Resources policy **45**: 239-246.

Cully, M., S. Bakhtiari, T. Bradley, H. Cotching, S. Couch, N. Drahos, M. Gibbons, K. Golobokova, M. Horne, L. Jones, K. Leong, A. Porta Cubas, K. Robertson, A. Swanepoel, R. Tuhin and C. Turnbull (2015). Australian Industry Report 2015. Canberra, Commonwealth of Australia.

Cunningham, M., L. V. Uffelen and M. Chambers (2019). "The Changing Global Market for Australian Coal." Reserve Bank of Australia Bulletin - September 2019: 28-39.

Della Vigna, M., Z. Stavrinou, A. Gandolfi, N. Snowdon and P. Young (2021). Carbonomics: Introducing the GS net zero carbon models and sector frameworks. Goldman Sachs Investment Research. London, Goldman Sachs Investment Research.

Department of Industry, S., Energy and Resources, (2018). Resources and Energy Quarterly, March 2018 - Iron Ore. S. Department of Industry, Energy and Resources. Canberra, Commonwealth of Australia.

Deryugina, T., F. Moore and R. S. J. Tol (2021). "Environmental applications of the Coase Theorem." Environmental science & policy **120**: 81-88.

Dewick, P., M. Bengtsson, M. J. Cohen, J. Sarkis and P. Schröder (2020). "Circular economy finance: Clear winner or risky proposition?" Journal of Industrial Ecology.

Dimmelmeier, A. (2023). "Sustainable finance as a contested concept: tracing the evolution of five frames between 1998 and 2018." Journal of sustainable finance & investment **13**(4): 1600-1623.

Dong-Hyun, K., L. Eul-Bum, J. In-Hyeo and A. Douglas (2019). "The Efficacy of the Tolling Model's Ability to Improve Project Profitability on International Steel Plants." Energies (Basel) **12**(7): 1221.

Doree, A. G. (2004). "Collusion in the Dutch construction industry: An industrial organization perspective." Building research and information : the international journal of research, development and demonstration **32**(2): 146-156.

Duc Huynh, T. L., T. Burggraf and M. A. Nasir (2020). "Financialisation of natural resources & instability caused by risk transfer in commodity markets." Resources policy **66**.

Dutschke, M. and A. Michaelowa (2003). "Development Aid and the CDM - How to Interpret "Financial Additionality"." Environment and Development Economics **11: 235–246**.

Edey, H. C., A. T. Peacock and R. A. Cooper (2003). National income and social accounting. London, Routledge.

Ellen MacArthur Foundation (2019). Completing the picture: How the circular economy tackles climate change (version 3).

Ellis, J., R. Baron and B. Buchner (2009). Sectoral approaches and the carbon market, OECD Publishing.

Emissions Reduction Assurance Committee (2022). Emissions Reduction Assurance Committee findings on the Emissions Reduction Fund's landfill gas generation method. Clean Energy Regulator. Canberra.

Eskander, S. and S. Fankhauser (2023). "The impact of climate legislation on trade-related carbon emissions 1996–2018." Environment and Resource Economics.

European Commission (2019). Accelerating the transition to the circular economy improving access to finance for circular economy projects. Luxembourg, Publications Office.

European Commission (2020). REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088. REGULATION (EU) 2020/852. European Commission. Brussels.

European Commission (2022). COMMISSION DELEGATED REGULATION (EU) 2023/363 amending and correcting the regulatory technical standards laid down in Delegated Regulation (EU) 2022/1288 as regards the content and presentation of information in relation to disclosures in pre-contractual documents and periodic reports for financial products investing in environmentally sustainable economic activities. T. E. Commission. Brussles. **Delegated Regulation (EU) 2022/1288**.

Fairbrass, A., G. Mace, P. Ekins and B. Milligan (2020). "The natural capital indicator framework (NCIF) for improved national natural capital reporting." Ecosystem services **46**: 101198.

Feaver, D. (2012). "Climate policy and border adjustment regulation : designing a coherent response." Melbourne Journal of International Law **13**(2): 792-817.

Ferlito, R. and R. Faraci (2022). "Business model innovation for sustainability: a new framework." Innovation & Management Review **19**(3): 222-236.

Ferro, M. S. (2019). Market definition in EU competition law. Northampton, MA, Edward Elgar Pub.

Finkel, A. (2021). "Message from the Chair - Technology Investment Roadmap: Low Emissions Technology Statement 2021." Retrieved 14 April 2022, from https://www.industry.gov.au/data-and-publications/technology-investment-roadmap-low-emissions-technology-statement-2021/message-from-the-chair.

Firouzi, A. and M. Vahdatmanesh (2019). "Applicability of Financial Derivatives for Hedging Material Price Risk in Highway Construction." Journal of Construction Engineering and Management **145**(5): 04019023.

Flick, U. and K. Metzler (2014). An introduction to qualitative research. Los Angeles, SAGE.

Fowler, H. W., F. G. Fowler and J. B. Sykes (1976). The Concise oxford dictionary of current English. Oxford, Clarendon Press.

Frank, M. Z. and T. Shen (2016). "Investment and the weighted average cost of capital." Journal of financial economics **119**(2): 300-315.

Friedman, M. (1962). Capitalism and Freedom. United States of America, University of Chicago Press.

Friedman, M. (1970). A Friedman doctrine-- The Social Responsibility Of Business Is to Increase Its Profits. The New York Times. New York, The New York Times Company.

Gamage, C., K. Ramirez, N. Yavorsky and L. Wright (2023). "Forging a clean steel economy in the United States." Rocky Mountain Institute Climate Aligned Industries https://rmi.org/forging-a-clean-steel-economy-in-the-united-states/ Accessed 13 March 2023.

Geels, F. W. and J. Gregory (2023). "Low-carbon reorientation in a declining industry? A longitudinal analysis of coevolving contexts and company strategies in the UK steel industry (1988–2022)." Energy research & social science **96**: 102953.

Geissdoerfer, M., P. Savaget, N. M. P. Bocken and E. J. Hultink (2017). "The Circular Economy – A new sustainability paradigm?" Journal of Cleaner Production **143**(C): 757-768.

Gelowitz, M. D. C. and J. J. McArthur (2018). "Insights on environmental product declaration use from Canada's first LEED® v4 platinum commercial project." Resources, conservation and recycling **136**: 436-444.

Ghaffar, S. H., M. Burman and N. Braimah (2020). "Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery." Journal of cleaner production **244**: 118710.

Ginga, C. P., J. M. C. Ongpeng and M. K. M. Daly (2020). "Circular Economy on Construction and Demolition Waste: A Literature Review on Material Recovery and Production." Materials **13**(13): 2970.

Giurco, D., A. Littleboy, T. Boyle, J. Fyfe and S. White (2014). "Circular Economy: Questions for Responsible Minerals, Additive Manufacturing and Recycling of Metals." Resources (Basel) **3**(2): 432-453.

Goodman, R. and D. Jinks (2003). "Toward an Institutional Theory of Sovereignty." Stanford law review **55**(5): 1749-1788.

Gordini, N. (2010). "Market-Driven Management: A Critical Literature Review." Symphonya(2): 97-109.

Green Industries South Australia (2020). Waste Strategy 2020-2025 Consultation Draft. Adelaide, Government of South Australia.

Greiner, S. and A. Michaelowa (2003). "Defining Investment Additionality for CDM projects—practical approaches." Energy policy **31**(10): 1007-1015.

Grubb, M., N. D. Jordan, E. Hertwich, K. Neuhoff, K. Das, K. R. Bandyopadhyay, H. van Asselt, M. Sato, R. Wang, W. A. Pizer and H. Oh (2022). "Carbon Leakage, Consumption, and Trade." Annual review of environment and resources **47**(1): 753-795.

Gupta, S. (2020). Industry Address. LME Metals Seminar, London, London Metal Exchange.

Hanrahan, P. (2021). The ABC of GBEs: A Guide to Government Business Enterprise Frameworks. Company Director Magazine. Sydney, Australian Institute of Company Directors. **July 2021**.

Hart, J., K. Adams, J. Giesekam, F. Pomponi and D. D. Tingley (2019). Barriers and drivers in a circular economy: the case of the built environment. 26th CIRP Life Cycle Engineering (LCE) Conference. Purdue University, West Lafayette, USA.

Hart, O. D. (1983). "The Market Mechanism as an Incentive Scheme." The Bell journal of economics **14**(2): 366-382.

Hausken, K. (2021). "The precautionary principle as multi-period games where players have different thresholds for acceptable uncertainty." Reliability engineering & system safety **206**: 107224.

Haywood, C. (2011). "Carbon Leakage - The First Mover Disadvantage: Australia's Trade-Related Assistance Measures for Emissions-Intensive, Trade-Exposed Industries." Review of European Community & international environmental law **20**(1): 78-90.

He, W., L. Tan, Z. J. Liu and H. Zhang (2020). "Property rights protection, environmental regulation and corporate financial performance: Revisiting the Porter Hypothesis." Journal of cleaner production **264**: 121615.

Heerdt, H. (2014). Green banks - the fairy tale of sustainability. Hamburg, Germany, Anchor Academic Publishing.

Helbling, T. (2020). "Externalities: Prices Do Not Capture All Costs." IMF Back to Basics Finance & Development Series.

Heller, H. (1966). "Optimal International Reserves." The Economic Journal: the Quarterly Journal of the Royal Economic Society **76**(302): 296.

Helm, D. (2011). "The sustainable borders of the state." Oxford Review of Economic Policy **27**(4): 517-535.

Helm, D. (2015). Natural capital : valuing our planet. New Haven, Yale University Press.

Helm, D. (2019). "Natural capital: assets, systems, and policies." Oxford review of economic policy **35**(1): 1-13.

Hervés-Beloso, C. and E. Moreno-García (2021). "Revisiting the Coase theorem." Economic Theory.

Hicks, J. R. (1939). "The Foundations of Welfare Economics." The Economic journal (London) **49**(196): 696-712.

Hina, M., C. Chauhan, P. Kaur, S. Kraus and A. Dhir (2022). "Drivers and barriers of circular economy business models: Where we are now, and where we are heading." Journal of cleaner production **333**: 130049.

Hites, B. (2020). "The growth of EAF steelmaking." Recycling Today Retrieved 26 September 2022, from https://www.recyclingtoday.com/article/the-growth-of-eaf-steelmaking/#:~:text=in%20the%20U.S.%2C%20are%20building,better%20part%20of%20a%20decade.

Hlousek, F. and J. McVeigh (2020). One man's trash is another man's treasure. Deloitte Legal. Prague, Deloitte.

Hogg, D. (2006). Impacts of unit-based waste collection charges. Working Group on Waste Prevention and Recycling. Paris, France, Organisation for Economic Cooperation and Development.

Hong, H., G. A. Karolyi and J. A. Scheinkman (2020). "Climate Finance." The Review of financial studies **33**(3): 1011-1023.

Hoornweg, D., P. Bhada-Tata and C. Kennedy (2013). "Environment: Waste production must peak this century." Nature **502**(7473): 615.

Hu, Q., Y. Peng, C. Guo, D. Cai and P. Su (2019). "Dynamic Incentive Mechanism Design for Recycling Construction and Demolition Waste under Dual Information Asymmetry." Sustainability (Basel, Switzerland) **11**(10): 2943.

Hua, C., C. Liu, J. Chen, C. Yang and L. Chen (2022). "Promoting construction and demolition waste recycling by using incentive policies in China." Environmental science and pollution research international **29**(35): 53844-53859.

IBIS World (2023). Iron smelting and steel manufacturing in Australia. Industry Report. Sydney, IBIS World. **C2110**.

Illankoon, I. M. C. S. and W. Lu (2020). "Cost implications of obtaining construction waste management-related credits in green building." Waste management (Elmsford) **102**: 722-731.

Iodice, S., E. Garbarino, M. Cerreta and D. Tonini (2021). "Sustainability assessment of Construction and Demolition Waste management applied to an Italian case." Waste management (Elmsford) **128**: 83-98.

Isenhour, C. (2019). A consuming globalism: on power and the post-paris politics of climate and consumption. Power and Politics in Sustainable Consumption Research and Practice, 1st Edition. M. M. Cindy Isenhour, Lucie Middlemiss. London, Routledge.

Ishak, A., A. Ilmar and W. Sitorus (2021). "Analysis of Government Policies in Structuring State Owned Corporation Through The Formation of Holding Companies." Jurnal Hukum Volkgeist **6**(1): 38-45.

Jakob, M. and M. Mehling (2023). Comparing policy options to address export-related carbon leakage: The role and potential of innovation support. Report, German Watch.

Jevons, W. S. (2013). The Theory of Political Economy. London, Palgrave Macmillan UK.

Jiménez-Rivero, A. and J. García-Navarro (2017). "Exploring factors influencing post-consumer gypsum recycling and landfilling in the European Union." Resources, Conservation & Recycling **116**: 116-123.

Jiménez Rivero, A., R. Sathre and J. García Navarro (2016). "Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union." Resources, Conservation & Recycling **108**(C): 171-181.

Jin, R., H. Yuan and Q. Chen (2019). "Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018." Resources, Conservation & Recycling **140**: 175-188.

Jotzo, F., T. Jordan and N. Fabian (2012). "Policy Uncertainty about Australia's Carbon Price: Expert Survey Results and Implications for Investment." Australian economic review **45**(4): 395-409.

Kaldor, N. (1939). "Welfare Propositions of Economics and Interpersonal Comparisons of Utility." The Economic journal (London) **49**(195): 549-552.

Keen, M., I. Parry and J. Roaf (2022). "Border carbon adjustments: rationale, design and impact." Fiscal studies **43**(3): 209-234.

Kellenberg, D. (2015). "The Economics of the International Trade of Waste." Annual Review of Resource Economics **7**: 109.

Kelly, A. (2022). Construction in Australia. Industry Report. Melbourne, IBIS World. **E**.

King, G., R. O. Keohane and S. Verba (1994). Designing social inquiry : scientific inference in qualitative research. Princeton, N.J, Princeton University Press.

Kirchherr, J., D. Reike and M. Hekkert (2017). "Conceptualizing the circular economy: An analysis of 114 definitions." Resources, Conservation and Recycling **127**: 221-3449.

Kliemt, H. (2012). Public Choice: A Methodological Perspective, Elsevier B.V**:** 765-798.

Korhonen, J., C. Nuur, A. Feldmann and S. E. Birkie (2018). "Circular economy as an essentially contested concept." Journal of Cleaner Production **175**: 544-552.

Kumari, T. and A. S. Raghubanshi (2023). Chapter 33 - Waste management practices in the developing nations: challenges and opportunities, Elsevier Inc**:** 773-797.

Kyriakopoulos, A. (2021). Scrap Metal Recycling in Australia. Specialised Industry Report. Sydney, IBIS World.

Kyriakopoulos, A. (2021). Waste Treatment and Disposal Services in Australia. Industry Report. Melbourne, IBIS World. **D2921**.

Lai, L. W. C., F. W. Ngar Ng and P. Yung (2007). "The Coase Theorem and a Coasian construction economics and management research agenda." Construction management and economics **26**(1): 29-46.

Latham, M. A., V. E. Schwartz and C. E. Appel (2011). "The intersection of tort and environmental law: where the twains should meet and depart." Fordham law review **80**(2): 737.

Leal Filho, W., U. Saari, M. Fedoruk, A. Iital, H. Moora, M. Klöga and V. Voronova (2019). "An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe." Journal of Cleaner Production **214**: 550-558.

Lèbre, É., G. Corder and A. Golev (2017). "The Role of the Mining Industry in a Circular Economy: A Framework for Resource Management at the Mine Site Level." Journal of Industrial Ecology **21**(3): 662-672.

Leonelli, G. C. (2022a). "Practical obstacles and structural legal constraints in the adoption of ‘defensive’ policies: comparing the EU Carbon Border Adjustment Mechanism and the US Proposal for a Border Carbon Adjustment." Legal Studies (2022), 42, 696–714.

Leonelli, G. C. (2022b). "Carbon Border Measures, Environmental Effectiveness and WTO Law Compatibility: Is There a Way Forward for the Steel and Aluminium Climate Club?" World trade review **21**(5): 619-632.

Leontief, W. (1970). "Environmental Repercussions and the Economic Structure: An Input-Output Approach." The Review of Economics and Statistics **52**(3): 262.

Liang, D., Z. Liu and Y. Bian (2021). "Match Circular Economy and Urban Sustainability: Re-investigating Circular Economy Under Sustainable Development Goals (SDGs)." Circular Economy and Sustainability **1**.

Liang, T., S. Wang, C. Lu, N. Jiang, W. Long, M. Zhang and R. Zhang (2020). "Environmental impact evaluation of an iron and steel plant in China: Normalized data and direct/indirect contribution." Journal of cleaner production **264**: 121697.

Lines, B. C., K. T. Sullivan, J. B. Smithwick and J. Mischung (2015). "Overcoming resistance to change in engineering and construction: Change management factors for owner organizations." International journal of project management **33**(5): 1170-1179.

Liu, Y., H. Li, H. An, J. Guan, J. Shi and X. Han (2021). "Are the environmental impacts, resource flows and economic benefits proportional? Analysis of key global trade routes based on the steel life cycle." Ecological indicators **122**: 107306.

Livermore, M. A., A. J. Glusman and G. Moyano (2013). Global Cost-Benefit Analysis, Oxford University Press.

Lo, A. Y. and R. Cong (2022). "Emission reduction targets and outcomes of the Clean Development Mechanism (2005–2020)." PLOS climate **1**(8): e0000046.

London, K., C. T. Formoso, V. Ruben and W. J. O'Brien (2008). Construction Supply Chain Management Handbook. Baton Rouge, Taylor & Francis Group.

London, K. A. and R. Kenley (2001). "An industrial organization economic supply chain approach for the construction industry: a review." Construction management and economics **19**(8): 777-788.

London Metal Exchange (2020). LME Monthly Overview June 2020, London Metal Exchange.

López Ruiz, L. A., X. Roca Ramón and S. Gassó Domingo (2020). "The circular economy in the construction and demolition waste sector – A review and an integrative model approach." Journal of cleaner production **248**: 119238.

Lu, W., X. Chen, D. C. W. Ho and H. Wang (2016). "Analysis of the construction waste management performance in Hong Kong: the public and private sectors compared using big data." Journal of cleaner production **112**: 521-531.

Luethi, S. (2010). "Effective deployment of photovoltaics in the Mediterranean countries: Balancing policy risk and return." Solar energy **84**(6): 1059-1071.

Luthi, S. and R. WÜStenhagen (2012). "The price of policy risk — Empirical insights from choice experiments with European photovoltaic project developers." Energy economics **34**(4): 1001-1011.

Luukkonen, T. (2000). "Additionality of EU framework programmes." Research policy **29**(6): 711-724.

Ma, S.-H., Z.-G. Wen, J.-N. Chen and Z.-C. Wen (2014). "Mode of circular economy in China's iron and steel industry: a case study in Wu'an city." Journal of Cleaner Production **64**: 505-512.

Maalouf, A. and A. Mavropoulos (2023). "Re-assessing global municipal solid waste generation." Waste management & research **41**(4): 936-947.

MacIntosh, A. (2022). The Emissions Reduction Fund's landfill gas method: An assessment of its integrity. Canberra, The Australian National University.

Maggetti, M., F. Gilardi and C. M. Radaelli (2013). Designing research in the social sciences. Los Angeles ;, Sage.

Magrini, C., A. Dal Pozzo and A. Bonoli (2022). "Assessing the externalities of a waste management system via life cycle costing: The case study of the Emilia-Romagna Region (Italy)." Waste management (Elmsford) **138**: 285-297.

Mahpour, A. (2018). "Prioritizing barriers to adopt circular economy in construction and demolition waste management." Resources, conservation and recycling **134**: 216-227.

Makinda, S. M. (1998). "Sovereignty and Global Security." Security dialogue **29**(3): 281-292.

Manninen, K., S. Koskela, R. Antikainen, N. Bocken, H. Dahlbo and A. Aminoff (2018). "Do circular economy business models capture intended environmental value propositions?" Journal of cleaner production **171**: 413-422.

Marín-Beltrán, I., F. Demaria, C. Ofelio, L. M. Serra, A. Turiel, W. J. Ripple, S. A. Mukul and M. C. Costa (2022). "Scientists' warning against the society of waste." The Science of the total environment **811**: 151359-151359.

Marín Durán, G. (2023). "Securing compatibility of carbon border adjustments with the multilateral climate and trade regimes." The International and comparative law quarterly **72**(1): 73-103.

Marsden, J. (1998). Reforming Public Enterprises: Australia. Public Management Service. Paris, Organisation for Economic Cooperation and Development.

Marshall, A. (2013). Principles of Economics. London, Palgrave Macmillan UK.

Masud, M. H., M. Mourshed, M. S. Hossain, N. U. Ahmed and P. Dabnichki (2023). Chapter 2 - Generation of waste: problem to possible solution in developing and underdeveloped nations, Elsevier Inc**:** 21-59.

Matheson, T. (2022). "Disposal is not free: fiscal instruments to internalize the environmental costs of solid waste." International tax and public finance **29**(4): 1047-1073.

Mathis, K. (2009). Efficiency Instead of Justice? Searching for the Philosophical Foundations of the Economic Analysis of Law. Dordrecht, Springer Netherlands.

Mazzucato, M. and J. Ryan-Collins (2022). "Putting value creation back into "public value": from market-fixing to market-shaping." Journal of economic policy reform **25**(4): 345-360.

McCarthy, A., R. Dellink and R. Bibas (2018). "The Macroeconomics of the Circular Economy Transition: A Critical Review of Modelling Approaches." (130).

McKibbin, W. J. and P. J. Wilcoxen (2002). Climate change policy after Kyoto : blueprint for a realistic approach. Washington, D.C, Brookings Institution Press.

Mehling, M. (2023). "Supply-side crediting to manage climate policy spillover effects." EPRG Working Paper **Cambridge Working Paper in Economics**.

Mehling, M. A., H. van Asselt, K. Das, S. Droege and C. Verkuijl (2019). "Designing Border Carbon Adjustments for Enhanced Climate Action." The American journal of international law **113**(3): 433-481.

Meyer, T. and T. N. Tucker (2022). "Trade and Climate, Law and Politics: A Response." World trade review **21**(1): 127-129.

Mhatre, P., V. V. Gedam, S. Unnikrishnan and R. D. Raut (2023). "Circular economy adoption barriers in built environment- a case of emerging economy." Journal of cleaner production **392**: 136201.

Michaelowa, A., L. Hermwille, W. Obergassel and S. Butzengeiger (2019). "Additionality revisited: guarding the integrity of market mechanisms under the Paris Agreement." Climate policy **19**(10): 1211-1224.

Minunno, R., T. O'Grady, G. M. Morrison and R. L. Gruner (2020). "Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building." Resources, conservation and recycling **160**.

Moneva, J. M., S. Scarpellini, A. Aranda-Usón and I. Alvarez Etxeberria (2023). "Sustainability reporting in view of the European sustainable finance taxonomy: Is the financial sector ready to disclose circular economy?" Corporate social-responsibility and environmental management **30**(3): 1336-1347.

Moscati, I. (2018). Measuring utility : from the marginal revolution to behavioral economics. New York, NY, Oxford University Press.

Moscati, I. (2020). History of utility theory. Bocconi Working Paper Series. Milan, Bocconi. **Working Paper No. 129**.

Mueller, D. (2003). Public choice III. Cambridge, U.K. ;, Cambridge University Press.

Muslemani, H., X. Liang, K. Kaesehage, F. Ascui and J. Wilson (2021). "Opportunities and challenges for decarbonizing steel production by creating markets for 'green steel' products." Journal of cleaner production **315**: 128127.

Muslemani, H., X. Liang, K. Kaesehage and J. Wilson (2020). "Business Models for Carbon Capture, Utilization and Storage Technologies in the Steel Sector: A Qualitative Multi-Method Study." Processes **8**(5): 576.

Nawaz, A., J. Chen and X. Su (2023). "Exploring the trends in construction and demolition waste (C&DW) research: A scientometric analysis approach." Sustainable energy technologies and assessments **55**: 102953.

Newaz, M. T., P. Davis, W. Sher and L. Simon (2020). "Factors affecting construction waste management streams in Australia." International journal of construction management: 1-9.

Nußholz, J., S. Çetin, L. Eberhardt, C. De Wolf and N. Bocken (2023). "From circular strategies to actions: 65 European circular building cases and their decarbonisation potential." Resources, Conservation & Recycling Advances **17**: 200130.

Nußholz, J. L. K., F. N. Rasmussen, K. Whalen and A. Plepys (2020). "Material reuse in buildings: Implications of a circular business model for sustainable value creation." Journal of Cleaner Production **245**.

O'Dwyer, B. and J. Unerman (2020). "Shifting the focus of sustainability accounting from impacts to risks and dependencies: researching the transformative potential of TCFD reporting." Accounting, auditing & accountability journal **33**(5): 1113-1141.

Oluleye, B. I., D. W. M. Chan, A. B. Saka and T. O. Olawumi (2022). "Circular economy research on building construction and demolition waste: A review of current trends and future research directions." Journal of cleaner production **357**: 131927.

Organisation for Economic Cooperation and Development (1998). Corporate Governance, State-Owned Enterprises and Privatisation. Paris, OECD Publishing.

Ortino, F. (2018). "The obligation of regulatory stability in the fair and equitable treatment standard: How far have we come?" Journal of international economic law **21**(4): 845-865.

Overland, I. and R. Sabyrbekov (2022). "Know your opponent: Which countries might fight the European carbon border adjustment mechanism?" Energy policy **169**: 113175.

Pandit, J., M. Watson and A. Qader (2020). Reduction of greenhouse gas emission in steel production final report. Melbourne, CO2CRC Ltd.

Papastamoulis, V., K. London, Y. Feng, P. Zhang, R. Crocker and P. Patias (2021). "Conceptualising the Circular Economy Potential of Construction and Demolition Waste: An Integrative Literature Review." Recycling (Basel) **6**(3): 61.

Pareto, V. (1906). Manual of political economy. London, Macmillan.

Parisi, F. (2004). The Efficiency of the Common Law Hypothesis. Boston, MA, Springer US**:** 519-522.

Parker, W. (2020). "Evidence and knowledge from computer simulation." Erkenntnis: An International Journal of Scientific Philosophy **Volume 87, pages1521–1538 (2022)**.

Parliament of New South Wales (2016). NSW Scrap Metal Industry Act.

Pellegrino, R., N. Costantino and D. Tauro (2019). "Supply Chain Finance: A supply chain-oriented perspective to mitigate commodity risk and pricing volatility." Journal of Purchasing and Supply Management **25**(2).

Pellegrino, R., B. Gaudenzi and G. A. Zsidisin (2020). The “True” Cost of Mitigating Commodity Price Volatility: Insights from Total Cost of Ownership and Real Options Approach. The Nature of Purchasing**:** 161-178.

Peng, Z., W. Lu and C. Webster (2022). "If invisible carbon waste can be traded, why not visible construction waste? Establishing the construction waste trading ‘missing market’." Resources, conservation and recycling **187**.

Pickin, J., P. Randell, J. Trinh and B. Grant (2018). National Waste Report. Canberra.

Pickin, J., C. Wardle, K. O'Farrell and L. Stovell (2022). National waste report 2022. National Waste Report. Canberra, Department for Climate Change, Energy, the Environment and Water.

Pickin, J., C. Wardle, K. O’Farrell, P. Nyunt and S. Donovan (2020). National Waste Report 2020. National Waste Report. Canberra, Department of Agriculture, Water and the Environment. **2020**.

Pieroni, M. P. P., T. C. McAloone and D. C. A. Pigosso (2019). "Business model innovation for circular economy and sustainability: A review of approaches." Journal of cleaner production **215**: 198-216.

Pigou, A. C. (1920). The economics of welfare. London, Macmillan.

Plöchl, C., W. Wetzer and A. Ragoßnig (2008). "Clean development mechanism: an incentive for waste management projects?" Waste management & research **26**(1): 104-110.

Ployhart, R. E. and R. J. Vandenberg (2010). "Longitudinal Research: The Theory, Design, and Analysis of Change." Journal of management **36**(1): 94-120.

Porter, M. E. (1990). The competitive advantage of nations. New York, Free Press.

Porter, M. E. and C. v. d. Linde (1995). "Toward a New Conception of the Environment-Competitiveness Relationship." The Journal of economic perspectives **9**(4): 97-118.

Posner, R. A. (1986). Economic analysis of law. Boston, Little, Brown.

Powell, J. T., M. R. Chertow and D. C. Esty (2018). "Where is global waste management heading? An analysis of solid waste sector commitments from nationally-determined contributions." Waste management (Elmsford) **80**: 137-143.

Prasad, S., F. Sakura, L. Adcock, J. Newman, S. Kasner, N. Sullivan, J. Philippe, H. Bjorg Gylfadottir, D. K. King, M. Wilson, B. Sichlau, R. Willis, C. Ho, K. Dodd, C. Smith and M.

Vahldiek (2022). State of circularity in Australia: Perspectives from the field. Sydney, Planet Ark.

Purchase, C. K., D. M. Al Zulayq, B. T. O'Brien, M. J. Kowalewski, A. Berenjian, A. H. Tarighaleslami and M. Seifan (2021). "Circular Economy of Construction and Demolition Waste: A Literature Review on Lessons, Challenges, and Benefits." Materials **15**(1): 76.

Rasheed, N., D. Khan, A. Gul and R. Magda (2023). "Impact Assessment of Climate Mitigation Finance on Climate Change in South Asia." Sustainability (Basel, Switzerland) **15**(8): 6429.

Rayack, E. (1987). Not so free to choose : the political economy of Milton Friedman and Ronald Reagan. New York, Praeger.

Read, R. and T. O'Riordan (2017). "The Precautionary Principle Under Fire." Environment : science and policy for sustainable development **59**(5): 4-15.

Robinson, J. V. (2017). "Market." Encyclopaedia Britannica Retrieved 5 May 2021, from https://www.britannica.com/topic/market.

Rojas, M., A. Routh, J. Sherwood, J. Buckley and A. Keyal (2022). Reshoring and "Friendshoring" Supply Chains. Government Trends 2022. New York, Deloitte Centre for Government Insights.

Rossetto, D. (2014). Case studies of climate resilience in urban areas and their funding. UNFCCC Standing Committee on Finance Annual Forum – Montego Bay, Jamaica, 21 & 22 June 2014. Montego Bay, UNFCCC.

Rossetto, D. (2015). "Green Financing: Potential Role for UN in Setting Standards for Green Bonds Ahead of Paris Talks." International Environment Reporter, Bloomberg BNA **VOL. 38, NO. 13**(New York).

Rossetto, D. (2017). "Defining Green Finance for Climate Change." Daily Environment Report, Bloomberg BNA **227 DEN 18**(New York).

Rossetto, D. (2019). "Carbon Markets Beyond 2020: Achieving Breakthrough on Paris Agreement." Bloomberg Law Journal, Environment & Energy Report.

Rossetto, D. (2023a). "The carbon border adjustment mechanism: What does it mean for steel recycling?" Sustainable Horizons **5**: 100048.

Rossetto, D. (2023b). "Relationships between sustainability disclosure, environmental innovation and performance: an examination of practice within the Australian construction and demolition waste sector." Environment, Development and Sustainability.

Rossetto, D. (2023c). "The relative importance of carbon markets to the waste management sector's future contribution to climate change commitments under the Paris Agreement: Insights from Australia." Springer Nature Carbon Neutrality **Volume 2**(Issue 2).

Rossetto, D. (2023d). "The long-term feasibility of border carbon mechanisms: An analysis of measures proposed in the European Union and the United States and the steel production sector." Sustainable Horizons **6**: 100053.

Rossi, F. and P. Morone (2023). "North–South Waste Trade: Prime Example of the Circular Economy or Major Environmental Threat?" Circular Economy and Sustainability.

Rowley, C. K. (1993). Public choice theory. Aldershot, Hants, England ;, Elgar.

Saldaña, J. (2021). The coding manual for qualitative researchers. London, SAGE Publishing.

Salman, S., C. Savindi, M. Tayyab and R. Tim (2020). "Using Recycled Construction and Demolition Waste Products: A Review of Stakeholders' Perceptions, Decisions, and Motivations." Recycling (Basel) **5**(31): 31-30.

Salman, S., M. Tayyab, S. P. W. Peter, K. Malik and J. Y. Rebecca (2021). "Extended Producer Responsibility in the Australian Construction Industry." Sustainability (Basel, Switzerland) **13**(620): 620.

Samuelson, P. A. (1958). Readings in economics. New York, McGraw-Hill.

Sandbag (2022). "European scrap steel floats away under carbon market incentives." https://sandbag.be/index.php/2022/09/22/european-scrap-steel-floats-away-under-carbon-market-incentives/ 2022.

Sandmo, A. (2000). The public economics of the environment. Oxford, Oxford University Press.

Schmidt, J., N. E. D. Helme, J. I. N. Lee and M. Houdashelt (2008). "Sector-based approach to the post-2012 climate change policy architecture." Climate policy **8**(5): 494-515.

Schmidt, M., M. Feth, A. Meyer, H. Rubel and Z. Felde. (2019). "The circular economy is here, and miners must adapt." Retrieved 29 June 2020, from https://www.mining-journal.com/forum/opinion/1372166/the-circular-economy-is-here-and-miners-must-adapt.

Schneider, L. (2009). "Assessing the additionality of CDM projects: practical experiences and lessons learned." Climate policy **9**(3): 242-254.

Sembiring, M. (2019). "Global Waste Trade Chaos: Rising Environmentalism or Cost-Benefit Analysis?" NTS Insight **No. IN19-02, July 2019**.

Setyowati, A. B. (2023). "Governing sustainable finance: insights from Indonesia." Climate policy **23**(1): 108-121.

Shao, S., Z. Hu, J. Cao, L. Yang and D. Guan (2020). "Environmental Regulation and Enterprise Innovation: A Review." Business strategy and the environment **29**(3): 1465-1478.

Shooshtarian, S., S. Caldera, T. Maqsood, T. Ryley and M. Khalfan (2022). "An investigation into challenges and opportunities in the Australian construction and demolition waste management system." Engineering, construction, and architectural management **29**(10): 4313-4330.

Shooshtarian, S., T. Maqsood, M. Khalfan, R. J. Yang and P. Wong (2020). "Landfill Levy Imposition on Construction and Demolition Waste: Australian Stakeholders' Perceptions." Sustainability (Basel, Switzerland) **12**(11): 4496.

Shooshtarian, S., T. Maqsood, P. Wong and R. Yang (2020). "Australian Construction and Demolition Waste Management System in Australia: Investigation of Challenges and Opportunities." Preprints.

Singhania, M. and N. Saini (2023). "Institutional framework of ESG disclosures: comparative analysis of developed and developing countries." Journal of sustainable finance & investment **13**(1): 516-559.

Smith, A. (1910). The wealth of nations. London, Dent.

Söderholm, P. and T. Ekvall (2019). "Metal markets and recycling policies: impacts and challenges." Mineral economics : raw materials report **33**(1-2): 257-272.

Soh Young, I. and K. Schumacher (2021). Carbonwashing: ESG Data Greenwashing in a Post-Paris World. Settling Climate Accounts: Navigating the Road to Net Zero, Palgrave Macmillan, Cham.

Spodniak, P. and V. Bertsch (2020). "Is flexible and dispatchable generation capacity rewarded in electricity futures markets? A multinational impact analysis." Energy **196**.

Stavins, R. N. (2003). Chapter 9 Experience with market-based environmental policy instruments, Elsevier B.V. **1:** 355-435.

Steffen, B. (2020). "Estimating the cost of capital for renewable energy projects." Energy economics **88**: 104783.

Streck, C. (2011). "Ensuring New Finance and Real Emission Reduction: A Critical Review of the Additionality Concept." Carbon & climate law review : CCLR **5**(2): 158-168.

Struthers, I. A., L. Herraiz, H. Muslemani, D. Su, C. Thomson and M. Lucquiaud (2022). Assessing the negative carbon emissions potential from the Waste-to-Energy sector in Europe (November 25, 2022). , Available at SSRN:. Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16) 23-24 Oct 2022. Lyon, International Energy Agency.

Su, P., Y. Peng, Q. Hu and R. Tan (2020). "Incentive Mechanism and Subsidy Design for Construction and Demolition Waste Recycling under Information Asymmetry with Reciprocal Behaviors." International journal of environmental research and public health **17**(12): 4346.

Tao, H., S. Zhuang, R. Xue, W. Cao, J. Tian and Y. Shan (2022). "Environmental Finance: An Interdisciplinary Review." Technological forecasting & social change **179**: 121639.

Taylor, B. (2023). "SSAB foresees premium for recycled-content steel." Recycling Today News https://recyclingtoday.com/news/ssab-steel-recycling-decarbonization-sweden-usa-price/?utm_campaign=Recycling+Today+Newsletter&utm_source=03%2f31%E2%80%A6.

Thomson, J. (2021). Waste Remediation and Materials Recovery Services in Australia. Industry Report. Melbourne, IBIS World. **D2922**.

Tong, X., H. Yu, L. Han, T. Liu, L. Dong, F. Zisopoulos, B. Steuer and M. de Jong (2023). "Exploring business models for carbon emission reduction via post-consumer recycling infrastructures in Beijing: An agent-based modelling approach." Resources, conservation and recycling **188**: 106666.

United Nations Environment Programme (2015). Global Waste Management Outlook. Nairobi, United Nations Environment Program & International Waste Management Association.

Wang, S., C. Yang and Z. Li (2022). "Green Total Factor Productivity Growth: Policy-Guided or Market-Driven?" International journal of environmental research and public health **19**(17): 10471.

Wasserbaur, R., T. Sakao and L. Milios (2022). "Interactions of governmental policies and business models for a circular economy: A systematic literature review." Journal of cleaner production **337**: 130329.

White House (2021). FACT SHEET: The United States and European Union To Negotiate World's First Carbon-Based Sectoral Arrangement on Steel and Aluminum Trade. Joint US-EU statement on Trade in Steel and Aluminium,. Government of the United States of America.

Williams, C. (2011). "Research Methods." Journal of business & economics research (Littleton, Colo.) **5**(3).

Winans, K., A. Kendall and H. Deng (2017). "The history and current applications of the circular economy concept." Renewable and Sustainable Energy Reviews **68**: 825-833.

Woiceshyn, J. and U. Daellenbach (2018). "Evaluating inductive vs deductive research in management studies." Qualitative research in organizations and management **13**(2): 183-195.

Wood, T., G. Dundas and J. Ha (2020). Start with Steel. Melbourne, Australia, Grattan Institute.

Wooders, P., G. Cook, P. Zakkour, M. Harfoot and S. Stiebert (2009). The role of sectoral approaches and agreements: Focus on the steel sector in China and India. Report Series. London, Climate Strategies.

World Steel (2012). Sustainable Steel at the Core of a Green Economy, World Steel Association.

Wu, H., J. Zuo, H. Yuan, G. Zillante and J. Wang (2020). "Cross-regional mobility of construction and demolition waste in Australia: An exploratory study." Resources, Conservation & Recycling **156**.

Wu, H., J. Zuo, H. Yuan, G. Zillante and J. Wang (2023). "Investigation of the social and economic impacts of cross-regional mobility of construction and demolition waste in Australia." Resources, conservation and recycling **190**: 106814.

Yellishetty, M. and G. M. Mudd (2014). "Substance flow analysis of steel and long term sustainability of iron ore resources in Australia, Brazil, China and India." Journal of cleaner production **84**: 400-410.

Yin, R. K. (2009). Case study research : design and methods. Thousand Oaks, Calif, Sage Publications.

Yin, R. K. (2018). Case study research and applications : design and methods. Los Angeles, SAGE.

Zannoni, D. (2020). "The legitimate expectation of regulatory stability under the Energy Charter Treaty." Leiden journal of international law **33**(2): 451-466.

Zaremba, A. (2019). "The Cross Section of Country Equity Returns: A Review of Empirical Literature." Journal of risk and financial management **12**(4): 165.

Zaremba, A., A. Szyszka, H. Long and D. Zawadka (2020). "Business sentiment and the cross-section of global equity returns." Pacific-Basin finance journal **61**: 101329.

Zharfpeykan, R. and C. Akroyd (2022). "Factors influencing the integration of sustainability indicators into a company's performance management system." Journal of cleaner production **331**: 129988.

Zhong, J. and J. Pei (2022). "Beggar thy neighbor? On the competitiveness and welfare impacts of the EU's proposed carbon border adjustment mechanism." Energy policy **162**: 112802.

Zink, T. and R. Geyer (2017). "Circular Economy Rebound." Journal of Industrial Ecology **21**(3): 593-602.

Zou, H. (2024). "The social welfare effect of environmental regulation: An analysis based on Atkinson social welfare function." Journal of Cleaner Production **Vol 434**.