DELFT UNIVERSITY OF TECHNOLOGY
& LEIDEN UNIVERSITY

INDUSTRIAL ECOLOGY MASTER THESIS

Cap Metric and LCA Weighted Permit Price Design Options for a Resource Cap-and-Trade System

DESIGNING A MATERIAL ALLOWANCE TRADING SCHEME (MATS) TO STEER EU ENVIRONMENTAL FOOTPRINT BELOW PLANETARY BOUNDARIES

Author:
Jorian van Bemmelen
L: 4077784, D: 4790413

Supervisors:
Dr. D.P. Peck - 1st
Drs. L.F.C.M. van Oers - 2nd

A thesis submitted to obtain
the Master of Science degree in Industrial Ecology.

June 12, 2026



Universiteit Leiden

TU Delft

Abstract

The persistent expansion of global material use and the subsequent transgression of planetary boundaries (PB's) necessitate a fundamental restructuring of European environmental governance. While the European Union has implemented various strategies under the green growth paradigm, including the Green Deal and the Circular Economy Action Plan, these frameworks have failed to achieve the absolute decoupling of economic activity from environmental degradation. Current policy efforts primarily focus on relative efficiency gains, which are consistently neutralised by the increasing volume of consumption and production. This research identifies a critical gap in the scientific discourse: while the necessity of resource caps is recognised, there remains a lack of concrete, conceptual designs for such regulatory instruments. Consequently, this thesis develops the Material Allowance Trading Scheme (MATS), a conceptual cap-and-trade framework designed to steer the EU's societal metabolism back within planetary boundaries.

The methodology integrates a literature review with a modelling exercise that utilises the functional architecture of the EU Emissions Trading System (ETS) as a blueprint. By synthesising literature through a problem-solution lens, the research identifies the gap between environmental research and governance, leading to the need for a macro-scale resource cap. The proposed MATS framework employs a mass-based regulated metric, specifically targeting a reduction in total material throughput. Aligning with the Planetary Boundary framework, the cap is set to converge toward a sustainable target of 5 to 8 tonnes per capita by 2050, aligning the EU's resource use with the planetary boundaries of the Earth system.

A central feature of the design is the implementation of an impact-weighted permit pricing mechanism. Recognising that different materials possess varying ecological footprints, the scheme utilises Life Cycle Assessment (LCA) data and the Distance-to-Target method to adjust permit costs. This ensures that high-impact materials carry a proportionally higher regulatory cost, thereby incentivising the market to prioritise low-impact alternatives. The regulation is designed to target extractors and importers, while incorporating Material Passports for finished goods to prevent leakage. The findings demonstrate that a resource cap-and-trade system is a technically feasible and theoretically grounded necessary instrument to steer the EU's environmental footprint below planetary boundaries. By bridging the gap between theoretical PB's and tangible policy formulation, this research provides a necessary foundation for the academic and political debate on absolute resource reduction. The MATS represents a shift from productivity-based governance toward a governance model defined by binding biophysical constraints.

For any questions about the content of this report, please contact the author Jorian van Bemmelen.

Acknowledgements

I would like to express my sincere gratitude to my supervisors, David Peck and Lauran van Oers, for their invaluable guidance, patience, and feedback throughout this thesis process. Their expertise in Industrial Ecology was instrumental in shaping the conceptual framework of the Material Allowance Trading Scheme (MATS). I am particularly grateful for their practical suggestions regarding indicator design, the integration of Life Cycle Assessment methodologies, and the application of planetary boundaries, which helped clarify the core arguments of this research. Their continuous encouragement and constructive critiques provided essential direction from the initial proposal to the final draft.

Among my family and friends that supported me throughout my research I would like to thank my father Ernst for his invaluable guidance throughout the research from the writing of the research proposal to the writing of the final versions of this report. The rest of my family and friends have been instrumental in the support of this research by creating an environment where I was able to think critically with a creative and academic curiosity.

Contents

Abstract i

Acknowledgements ii

List of Definitions v

1 Introduction 1
- 1.1 The current state of the environment and environmental policy . . . 2
- 1.2 Problem Statement, Research Aim & Research Questions . . . 4
  - 1.2.1 Problem statement . . . 4
  - 1.2.2 Research Aim . . . 4
  - 1.2.3 Main Research Question . . . 4
  - 1.2.4 Sub-Research Questions . . . 4
  - 1.2.5 Research Scope . . . 4

2 Methodology 6
- 2.1 Literature Review Methodology . . . 6
  - 2.1.1 Overall Review Design . . . 6
  - 2.1.2 Search Strategy . . . 6
  - 2.1.3 Study Selection and Eligibility Criteria . . . 8
- 2.2 MATS development . . . 8
  - 2.2.1 Overall Research Design: Modelling a Conceptual Regulation . . . 9
  - 2.2.2 Relation to Policy Design Method . . . 9
- 2.3 Consideration of other Methods . . . 9
- 2.4 Answering the research questions . . . 10

3 Literature Review 11
- 3.1 Theme 1: Ecological Problem Space . . . 11
  - 3.1.1 Topic 1: Exceeding Planetary Boundaries . . . 11
  - 3.1.2 Topic 2: EU's Societal Metabolism . . . 13
  - 3.1.3 Summary of Theme 1 . . . 13
- 3.2 Theme 2: Governance Problem Space . . . 14
  - 3.2.1 Topic 3: Limits of the Green Growth Paradigm . . . 14
  - 3.2.2 Topic 4: Attempts at Sustainable Policy Design . . . 14
  - 3.2.3 Topic 5: Absence of Adequate Institutional Policy . . . 16
- 3.3 Theme 3: Policy Solution Ingredients . . . 16
  - 3.3.1 Topic 6: Principles of Governance . . . 16
  - 3.3.2 Topic 7: Available Policy tools . . . 17
  - 3.3.3 Topic 8: EU Governance Style . . . 17
  - 3.3.4 Summary: Preliminary line of reasoning behind resource law . . . 17
- 3.4 Topic 9: EU Material Cap-and-trade System, Towards European Environmental Policy within Planetary Boundaries . . . 18

3.4.1 Key Design Aspects for a Resource Cap-and-trade System . . . 18
3.4.2 Resource Cap Conceptual Design Criteria . . . 20
3.5 Summary . . . 20

4 Material Cap-and-Trade Regulation Design **21**
4.1 Material Cap-and-Trade Regulation Cap Design . . . 22
4.1.1 The Regulated Metric . . . 22
4.1.2 The material consumption indicator for cap setting . . . 27
4.1.3 The Cap Sizes and Reduction Goal . . . 28
4.1.4 Reflection of Literature on Regulated Metric . . . 30
4.2 Material Cap-and-Trade Regulation Permit Design . . . 30
4.2.1 Normalisation and Weighting . . . 31
4.2.2 Problems with directly implementing N&W values . . . 36
4.2.3 Further Research on Permit Pricing . . . 36
4.3 Proposed regulatory framework, the Material Allowance Trading Scheme . . . 37
4.4 Explanation MATS . . . 38
4.4.1 Why is MATS needed? . . . 38
4.4.2 How the System Works . . . 39
4.4.3 Who Is Affected . . . 39
4.5 Material Cap-and-Trade Regulation Design Summary . . . 40

5 Discussion **41**
5.1 Recap of Results . . . 41
5.1.1 Literature Review Results . . . 41
5.1.2 MATS design Results . . . 42
5.1.3 Main findings . . . 42
5.2 Implications of the Resource Cap . . . 42
5.2.1 MATS within the Policy Landscape . . . 44
5.3 Limitations of the research . . . 46
5.3.1 Literature Review Limitations . . . 46
5.3.2 MATS Design Limitations . . . 46
5.4 Contribution to Academic Debate . . . 48
5.5 Answering the Research Question . . . 48
5.5.1 Summary of Discussion & Final Remarks . . . 49

6 Conclusion **50**
6.1 Further Research . . . 52

Bibliography **53**

List of Definitions

Societal Metabolism	The total flow of energy and materials that a society extracts from the environment, transforms through economic activities, and returns as waste and emissions to sustain its structures and functions.
Planetary Boundaries	Planetary boundaries define the safe operating space for humanity regarding the Earth's biophysical systems, establishing critical thresholds across nine global processes, including climate change, biodiversity loss, freshwater use, and ocean acidification, that must not be transgressed to prevent catastrophic and irreversible environmental destabilization. Introduced by Johan Rockström and a team of international scientists in 2009, this framework shifts the environmental governance paradigm from managing local pollution to enforcing absolute, biophysically determined limits on human activity. Transgressing these boundaries risks triggering dangerous tipping points that could disrupt the stable, Holocene-like state of the planet that has allowed human civilisation to thrive.
Decoupling	Decoupling occurs when an economic indicator (such as GDP) continues to grow while an environmental pressure or impact (such as CO2 emissions or material consumption) remains stable or declines. It is the primary goal of "green growth" strategies, aiming to break the historical correlation between economic wealth and ecological degradation.
Resource Cap	A resource cap is a legally binding target designed to reduce or limit the absolute consumption of individual materials or material groups (including biomass, fossil fuels, minerals, and metals). It serves as an economy-wide legal mechanism to ensure that aggregate resource use is brought within science-backed sustainable limits and planetary boundaries.
Regulated Metric	A regulated metric is the standardised unit of measurement defined by a regulatory framework to quantify and monitor the specific activity being governed. It serves as the legal and accounting basis for compliance, determining exactly what units must be tracked and reported by a regulatory system.
Life Cycle Analysis (LCA)	Life Cycle Assessment (LCA) is a structured, comprehensive, and internationally standardized (ISO 14040/14044) method used to evaluate the total environmental impacts associated with all stages of a product, process, or service's life cycle. This holistic evaluation traditionally spans from raw material extraction ("cradle") through manufacturing, distribution, and use, all the way to final disposal or recycling ("grave").

Chapter 1

Introduction

As global environmental pressures continue to escalate beyond biophysical limits, industrial activity remains a primary driver of planetary boundary transgression. Current European environmental policy, largely focused on the green growth paradigm and circular economy efficiency gains, has failed to achieve the absolute decoupling necessary to return the EU's societal metabolism to a safe operating space. This research addresses a critical gap in the scientific literature, the mismatch between scientific knowledge on planetary boundaries and effective policy mechanisms that are able to reduce the EU's environmental footprint below planetary boundaries. The central aim of this research is to develop a conceptual material cap-and-trade EU regulation, the Material Allowance Trading Scheme (MATS), to steer the European Union's environmental footprint below planetary boundaries.

This is the report of a master thesis for the Industrial Ecology master program from Leiden University and Delft University of Technology[1]. This report also serves the purpose of a scientific paper, and might also contribute practical implications on future EU policy.

From the perspective of Industrial Ecology, this research aims to contribute to the discussion on resource caps with the preliminary design of a cap regulated metric and Life Cycle Analysis (LCA) weighted permit price. Using a literature review and a modelling exercise, the conceptual design of a EU regulation aims to solve the gap between the environmental impacts caused by the EU's exceeding planetary boundaries and effective EU environmental policy (not environmental policy in the sense of fishing quota's, but large scale regulations such as the EU Green Deal and the EU ETS). A resource cap is defined in the List of Definitions as: *"A resource cap is a legally binding target designed to reduce or limit the absolute consumption of material groups (including biomass, fossil fuels, minerals, and metals). It serves as an economy-wide legal mechanism to ensure that aggregate resource use is brought within science-backed sustainable limits and planetary boundaries"*. The regulated metric is defined in the List of Definitions as: *"A regulated metric is the standardised unit of measurement defined by a regulatory framework to quantify and monitor the specific activity being governed. It serves as the legal and accounting basis for compliance, determining exactly what units must be tracked and reported by a regulatory system."*. LCA and LCA weighting are also defined in the List of Definitions. With the definition of the terms established, we now focus on the results found in this research.

The results, elaborated in chapter 4, the Material Allowance Trading Scheme functions as a mass-based resource cap-and-trade system where individual materials are capped. Figure 1.1 shows a visual summary of the proposed framework. The research does acknowledge multiple design options are suitable, and the results can be summarised in arguments that argue for and against different design options. Each design option must be studied in further research, as this

[1] https://www.universiteitleiden.nl/en/education/study-programmes/master/industrial-ecology

research is a first design aimed to contribute to the scientific debate on resource caps. Although other options are explored within this report, the mass-based option was elaborated most for the purpose of establishing a scrutanisable starting point for further scientific discussion. The system caps the mass of the materials from imported goods and extracted materials within the EU. The environmental impact of those materials are not directly capped, but as all materials are capped individually, the environmental impact of the cumulative materials is capped indirectly, meaning, since the total material footprint of the EU is capped, the environmental footprint is capped as well. This is based on the assumption that there is a linear relationship between material footprint and environmental footprint, as long as the distribution of different materials remains the same. Directly capping environmental impact was found less feasible, as the environmental impact cannot be measured like mass can be measured. A calculation of the impacts is required, which is less transparent for importers than mass measurements. The front end of the regulation uses mass as measurable indicator, and in the back end, the environmental impacts are calculated and governed. Further elaboration on the design considerations of the regulated metric can be found in subsection 5.1.2. The calculation of the environmental impacts and their reductions are not within the scope of this research. As will be elaborated in the literature review, the material footprint of the EU is the cause of the EU's environmental footprint. The material footprint consists of a variety of material flows; iron ore shipments, natural gas imports, wood imports, grain imports, electronics imports, building materials imports, and many more. As the material inflows are the cause of the environmental footprint, this report emphasises the approach of governing material inflows. Centralising the environmental impact as main focus of the regulatory framework is another approach. The material flow emphasis was chosen as method due to multiple reasons explained throughout this report.

With the results established, we rewind to the start for the full research approach. First, the context for the research is established in section 1.1, and the problem statement, research aim and research questions will be discussed in section 1.2. chapter 2 covers the methods used in this thesis. chapter 3 concerns the data collection used for the policy design in the subsequent chapter. chapter 4 concerns the policy design where the data from the previous chapter is used to model an EU cap-and-trade regulation. The results of chapter 3 and chapter 4 will be discussed in chapter 5. The final chapter 6 presents a conclusion of the report.

The established reporting layout for Industrial Ecology theses (Introduction, Literature, Research Questions, Methods, Results, Discussion, Conclusion & Recommendations (similar to the IMRD report layout)) was modified in this thesis to accommodate the multidisciplinary research approach.

1.1 The current state of the environment and environmental policy

As the state of the environmental is pushed to the background of public discourse and international policy, the impacts on the environment increase further beyond planetary boundaries (Kitzmann et al., 2025). Global material use continues to increase despite international and regional policy efforts aimed at achieving sustainability (European Environment Agency, 2024; OECD, 2019; Wiedmann et al., 2015). Even within the European Union, where the Circular Economy Action Plan seeks to decouple economic growth from resource use, the Domestic Material Input of the EU continues to rise (Krausmann et al., 2009; MaterialFlows.net, 2025). Economic expansion and consumption patterns increase more rapidly than the environmental gains achieved through efficiency and recycling (Haberl et al., 2020; Parrique, Barth, and Briens, 2019). As a result, absolute decoupling between economic growth and the environmental impacts of material use has not occurred and is unlikely to occur in the near future (European Academies Science Advisory Council, 2024; OECD, 2001; Parrique, Barth, and Briens, 2019).

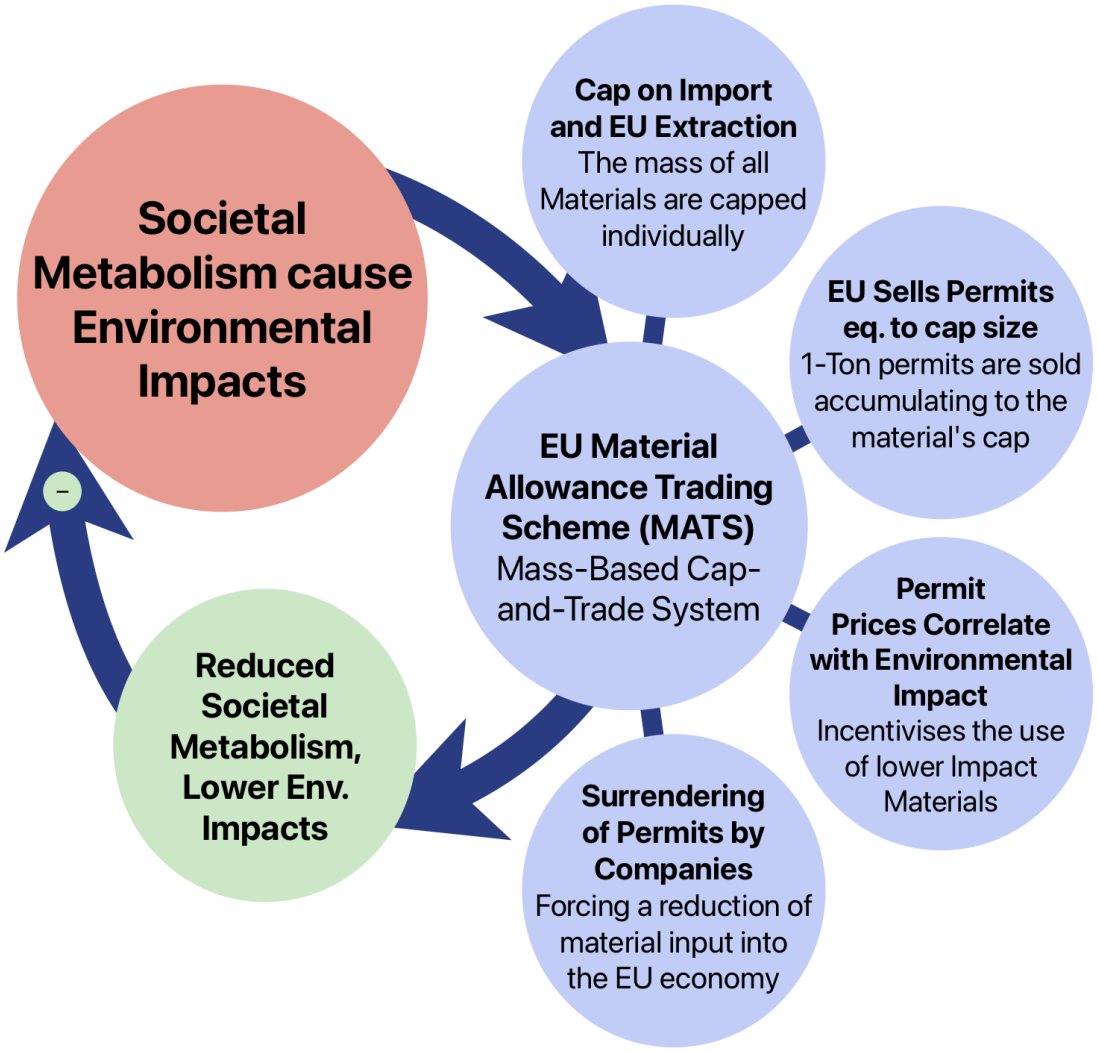


FIGURE 1.1: Material Allowance Trading Scheme (MATS) Framework

This challenges the central premise of "green growth" (International Institute for Sustainable Development, 2005).

In order to steer the EU's societal metabolism[2] to levels below the planetary boundary[3], current policies are inadequate and a need for alternative EU regulations is expressed that regulate the problem at the core (Meysner, Gore, and IEEP, 2022; Kelly, 2024; Ekins et al., 2014). The literature calls for resource law that limits the import and extraction of materials towards and within the EU such that the societal metabolism no longer exceed planetary boundaries. As the debate on such resource law lacks a concrete policy design to analyse, the conceptual development of the regulation is identified as research gap in the literature (Kelly, 2024, p. 10).

[2]Societal metabolism defined in subsection 3.1.1 as: "the total flow of energy and materials that a society extracts from the environment, transforms through economic activities, and returns as waste and emissions to sustain its structures and functions"

[3]Planetary Boundaries: (Rockström et al., 2009)

1.2 Problem Statement, Research Aim & Research Questions

Given the context of the research, this section will cover the resulting problem statement, research aim, and research questions.

1.2.1 Problem statement

The scientific discussion on resource use caps has until now been a summary of generalised discussion on potential ramifications of the regulation in question. Furthering the scientific discussion requires the conceptual development of the regulation. Therefore, the problem aimed to be solved in this thesis is this missing conceptual regulation design in literature.

1.2.2 Research Aim

The research aim of this thesis is to develop a conceptual material cap-and-trade EU regulation that will steer the EU environmental footprint below planetary boundaries. This thesis adds to the literature an attempt to translate scientific knowledge of planetary boundaries to concrete policy. As the conceptual design of the regulation has not yet been attempted in literature, the conceptual design presented within this thesis presents a novel and innovative framework for reflection within this thesis and for further examination by further research.

Due to the possible implications of the resulting conceptual regulation design, extra caution and scholarly restraint is required to acknowledge the potential negative implications can result from misinterpreted results and recommendations. To this end, this report is the best attempt at a meaningful and thought-out foundation for further research on the topic.

1.2.3 Main Research Question

Resulting from the problem statement from subsection 1.2.1 and the research aim from subsection 1.2.2, the following main research question is established:

What regulatory framework can advance the scientific discussion on future EU regulations capable of reducing the EU's environmental footprint below planetary boundaries?

1.2.4 Sub-Research Questions

The main research question will be answered by answering the following sub-research questions:

1. What regulatory framework can potentially steer the EU's environmental footprint below planetary boundaries?
2. What are the main design elements for applying a cap-and-trade system to resource use?
3. How does policy design transform the resource cap to conceptual EU regulation?

1.2.5 Research Scope

The goal of the thesis is to develop a preliminary design of an EU cap-and-trade regulation that limits the environmental footprint of the EU's economy within planetary boundaries. The regulation is modelled after the EU ETS and the main aspects of the regulation that are considered in this thesis are the design of the regulated metric of the cap, and the permit price,

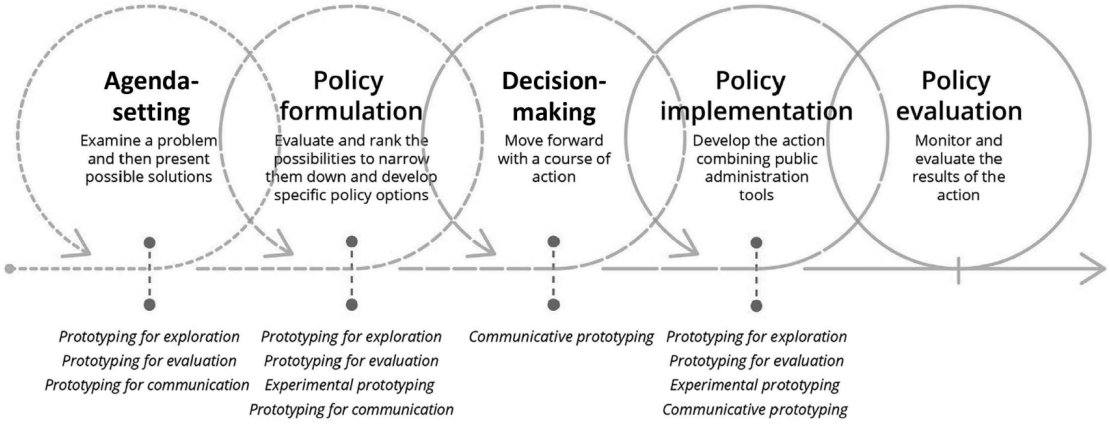


FIGURE 1.2: Howlett Policy Cycle (Howlett, 2023, p. 131)

visualised in Figure 1.1. Other components of the regulation will be briefly discussed to indicate the preliminary functioning of the regulation. Within the literature review, different societal and economic implications are identified which will be discussed. Therefore, the scope of this thesis is to preliminarily design the regulation, and identify and explore the societal and economic implications of the regulation. The conceptual design of the regulation will be a regulation design built on literature and EU policy design knowledge. Some methods at the core of Industrial Ecology were used during the research such as systems thinking, where the problem is analysed and a solution to the system was developed, Life Cycle Analysis (LCA) was used for the environmental impact assessment, and a form of Material Flow Accounting (MFA) was used in the form of material indicators such as, Material Footprint (MF), Domestic Material Consumption (DMC) and Direct Material Input (DMI).

The scope of the regulation design is the Agenda-setting and Policy Formulation steps of the Howlett policy cycle (Howlett, 2023). Figure 1.2 shows the visualisation of the policy cycle. What falls outside of the scope of this research is the full application of the Agenda-setting and Policy formulation phases such as Prototyping for communication and Prototyping for evaluation. The latter phases Decision-making, Policy implementation and Policy evaluation obviously fall outside the scope of this research as well.

A full design of the regulation is outside the scope of this report. This approach was required for the limited time available for this research, and suitable for a starting point for further discussion. The answers to the societal and economic implications will also stay largely unanswered. The questions cover a variety of disciplines such as law, economics, political science and policy design that require a level of expertise beyond the author's abilities.

Chapter 2

Methodology

In section 1.2, we have identified research questions aimed at filling the existing gap between EU regulation and scientific knowledge of planetary boundaries and the need to reduce the EU's material footprint. This chapter aims to outline the research methods used in this thesis.

From the initial literature review in section 1.1, a possible solution for this gap is identified to be a cap-and-trade system that limits the material footprint, and therefore the environmental impact of the EU. The aim of this thesis articulated in subsection 1.2.2 is to develop a conceptual design of the regulation in order to reflect and have a scientific discussion on the regulation itself, which will be the scope of this research. The literature review methodology described in section 2.1 serves as the reasoning behind-, and data input for the conceptual policy design from chapter 4.

2.1 Literature Review Methodology

This chapter describes the methods used to conduct a traditional (narrative) literature review, structured around a problem–solution perspective. The literature review method is conducted by developing a custom approach based on literature review methods from literature (Snyder, 2019; Xiao and Watson, 2019; Kraus et al., 2022; Chigbu, Atiku, and Plessis, 2023).

2.1.1 Overall Review Design

The review adopts a traditional/narrative literature review design, with systematic elements in searching, screening, and synthesis. The problem–solution lens structures the review around identifying and clarifying the core research problem(s) in the field, and mapping and evaluating the range of solution options proposed in the literature. This aligns with guidance that literature reviews should articulate clear foci, methods, and contributions as independent studies (Snyder, 2019; Kraus et al., 2022; Chigbu, Atiku, and Plessis, 2023).

2.1.2 Search Strategy

The following explicit and robust search procedures are used in the literature review. The databases searched are Google Scholar and sources searched are peer reviewed academic literature. An unrestricted time frame was used in the search phase where later selection of the literature focused on the more recent literature. The only language used in the search phase was English. All relevant search results were saved in a Zotero library which can be requested from the author. A selection of the library was selected and used in this report. In this literature review, 9 topics were identified where each topic emerged from the previous topic. For each topic, the exemplary search queries from Table 2.1 were among the search queries used.

TABLE 2.1: Topics studied in the Literature Review

Topic No.	**Topic Name**	**Exemplary Search Queries**
1	Exceeding Planetary Boundaries	"planetary boundaries" framework "safe operating space" 2009..2026, "planetary boundaries" AND "material consumption" AND "absolute limits", "downscaling" planetary boundaries to "national level" OR "EU"
2	EU's Societal Metabolism	"societal metabolism" AND "material flow analysis" AND "environmental impact", "biophysical" basis of "societal metabolism" 2020..2026, "urban metabolism" AND "resource governance" AND "planetary boundaries"
3	Limits of Green Growth Paradigm	"absolute decoupling" vs "relative decoupling" GDP "resource use", "green growth" paradigm critique "planetary boundaries" 2018..2026, empirical evidence "decoupling" GDP "material footprint" high-income countries
4	Alternatives to Green Growth Policies	"post-growth" OR "degrowth" governance "policy frameworks", "steady-state economics" AND "resource throughput" AND "governance", "doughnut economics" AND "policy implementation" AND "EU member states"
5	Absence of Adequate Institutional Policies	"institutional barriers" to "absolute reduction" of "material consumption policies", "governance gap" AND "planetary boundary overshoot" AND "policy failure", "transformative governance" AND "lock-in" AND "resource extraction"
6	Principles of Governance	"principles of governance" for the "Anthropocene", "policy design" theory "Howlett" AND "systemic change", "sustainability transitions" AND "principles"
7	Available Policy Tools	"techniques of regulation" Morgan Yeung "command" "competition", "market-based instruments" vs "command and control" resource management, "demand-side" policy instruments "sufficiency" AND "efficiency"
8	EU Governance Style	"European environmental policy style" AND "competition governance", "EU Green Deal" AND "administrative space" AND "regulatory trends", "new modes of governance" in EU environmental law 2020..2026
9	EU Material cap-and-trade System	"Material cap-and-trade" system "regulation" AND "material consumption", integrating "biophysical limits" into "macroeconomic policy" EU, "science-policy interface" AND "resource law" AND "conceptual design"

The topics were categorised under 3 main themes (Ecological Problem, Governance Problem, and Solution Ingredients) and these themes were further categorised in a problem space and a solution space. Figure 2.1 shows the resulting visualisation of the literature converging to the solution identified in this thesis.

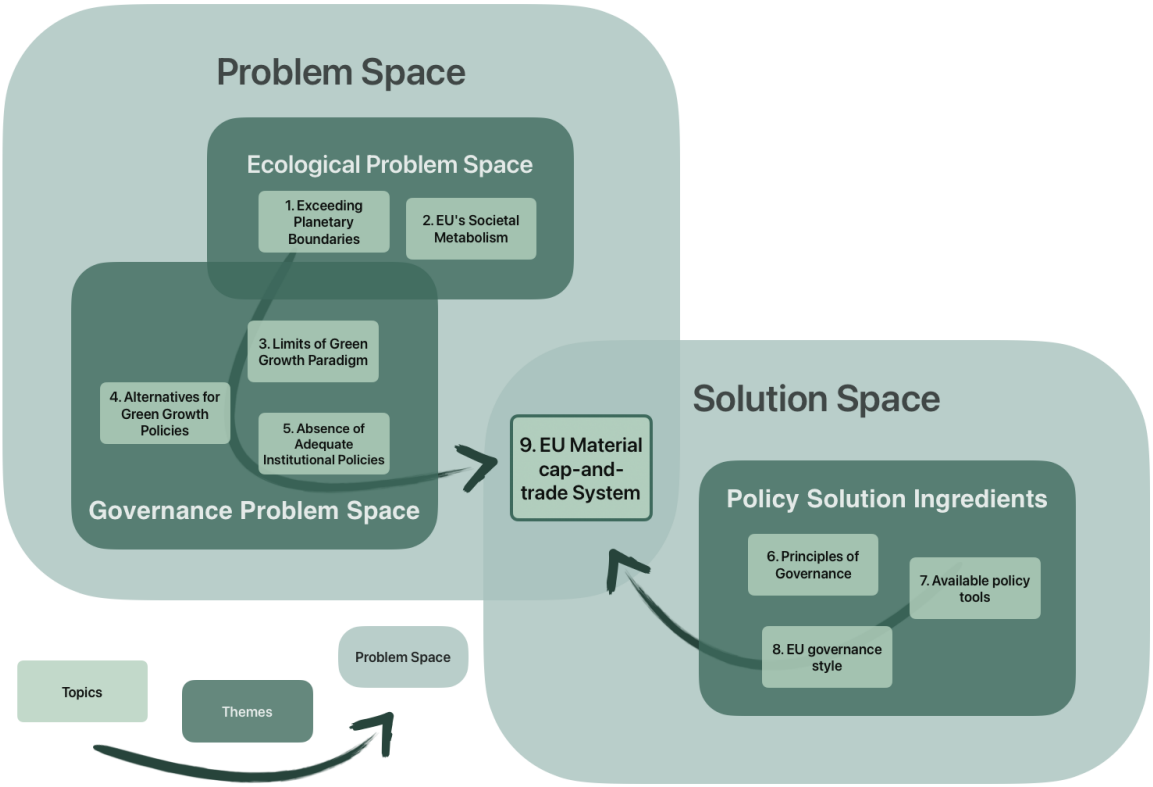


FIGURE 2.1: Literature Iterations

2.1.3 Study Selection and Eligibility Criteria

The quality of the literature was evaluated using the following selection criteria to select the most relevant literature for this research.

The inclusion criteria included: Peer-reviewed publications addressing the defined problem, studies proposing, evaluating, or theorizing solution options (policies, practices, frameworks, methods), and conceptual, theoretical, and empirical works contributing to understanding or addressing the problem.

The exclusion criteria included: Publications not directly related to the focal problem or that mention it only tangentially, non-scholarly sources where methodological quality could not be assessed. Screening proceeded in stages (title, abstract, then full text), consistent with systematic review guidance and the Search/AppraisaL stages of the SALSA framework (Xiao and Watson, 2019; Grant and Booth, 2009).

The resulting literature was then further selected and interpreted for which the results are presented in chapter 3.

2.2 MATS development

This thesis develops a conceptual EU regulation modelled on the EU ETS. The research is methodological in two senses: it uses modelling as an overarching (broad) method, and literature review plus case study as specific (narrow) methods for data collection and processing. The approach imitates elements of policy design and design-thinking rather than applying any

one formal design method in full. The results from the MATS development are covered in chapter 4.

2.2.1 Overall Research Design: Modelling a Conceptual Regulation

The thesis is structured as a modelling exercise, in which existing policy (the EU ETS) is used as a blueprint and input data from literature is transformed into a new conceptual regulatory design. In the philosophy of science, models are understood as central instruments that represent phenomena and allow reasoning about possible systems and futures (Frigg and Hartmann, 2018).

The model of the new regulation is treated as a structural representation of a possible policy system: it mirrors key relations and mechanisms of the EU ETS while being adapted to a different regulatory problem.

2.2.2 Relation to Policy Design Method

The modelling of public policies is often approached through a formal policy design method, which systematically links the examined problem, possible policy solutions, and policy prototypes (Howlett, 2023). This thesis does not apply a full policy design methodology. Instead, it selectively imitates two stages of the policy cycle, understood as core design moments: Agenda-setting and Policy formulation from the policy cycle visualised in Figure 2.2. The agenda setting represents the identification and justification of the problem, drivers, and needs for EU-level regulation, for which literature review is used as method. Policy formulation is used to develop the structure and instruments of the conceptual regulation (MATS), using EU ETS as a reference. A case study of the EU ETS and literature review is used in this phase.

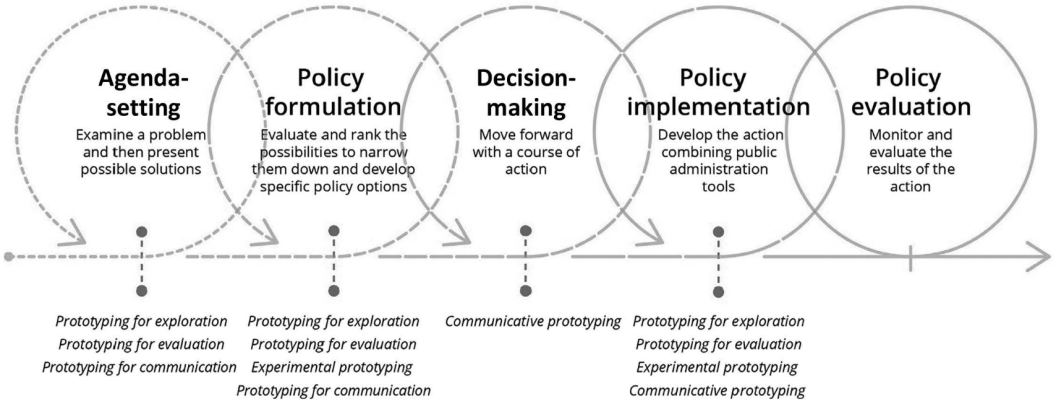


FIGURE 2.2: Policy design phases from the Policy Cycle method (Howlett, 2023, p. 131)

2.3 Consideration of other Methods

Other methods, such as interviews with policymakers, experts, or stakeholders, are recognised as potentially valuable for informing both agenda-setting and design choices. For example, policy design literature addresses how information from various sources can feed into instrument choice and policy mixes (Howlett, 2023).

However, this thesis does not employ interviews or other primary empirical methods. The methodological focus is deliberately on modelling from existing knowledge (secondary literature and a single, detailed case study), consistent with the aim of building a conceptual regulation rather than evaluating an existing policy in practice.

2.4 Answering the research questions

The methods used to answer the research questions will comply with the following The first research question will be answered in literature chapter 3 using the literature review methods from section 2.1. The second research question will be answered in the MATS design chapter 4 using the conceptual design methods described in section 2.2. The third sub-research question will be answered by combining the literature with the policy design to answer how the design of the regulation transforms the resource cap to conceptual EU regulation. The main research question will be answered from the combination of the answers from sub-research question 1, 2 and 3 using the corresponding methods.

Chapter 3

Literature Review

In chapter 1, a literature review in this chapter was announced as the first part of the results of this thesis. The methods used in this chapter are described in section 2.1 to answer the first sub-research question: What regulatory framework can potentially steer the EU's environmental footprint below planetary boundaries? The literature review is structured in themes and topics, where the 9 specific topics are categorised under the 3 themes. The 3 themes are Theme 1: Ecological Problem Space in section 3.1, Theme 2: Governance Problem Space in section 3.2, and Theme 3: Policy Solution Ingredients in section 3.3. The outcome of the literature is presented in section 3.4, and the results are summarised in section 3.5.

3.1 Theme 1: Ecological Problem Space

The ecological problem space identifies how planetary boundaries, resource use (commodities like raw materials, materials and end products consumed by society), and societal metabolism interconnect, by applying the Industrial Ecology systems thinking perspective. By translating the planetary boundaries framework to societies metabolism, the core problem of environmental impact is identified which can be later transformed into actionable policy.

3.1.1 Topic 1: Exceeding Planetary Boundaries

The transgression of planetary boundaries represents the central ecological crisis of the Anthropocene, indicating that human activities have pushed Earth-system processes beyond the stable holocene-like state that has supported human civilization (Rockström et al., 2009; Steffen et al., 2015). These boundaries define the biophysical limits within which humanity can safely operate without triggering irreversible environmental shifts. According to the planetary boundaries, current human activities vastly overshoot these limits as visualised in Figure 3.1 (Kitzmann et al., 2025). Translating the planetary boundaries framework to material consumption has made the cause of the exceeding planetary boundaries more tangible (Sala et al., 2020). Linking the perspectives of material consumption and planetary boundaries shows the causation between human activities and their environmental impact, which will be elaborated in coming sections. This results in the fundamental principle behind planetary boundaries; as human activity increases, the environmental impacts increase as well. The resource use of the world and different regions can be transformed to actionable policy that targets the problem at the core (O'Neill et al., 2018). Put concretely, global extraction now reaches approximately 90 Gt per year, far above the roughly 50 Gt/yr "boundary" level proposed by resource ecologists (Hickel et al., 2022).

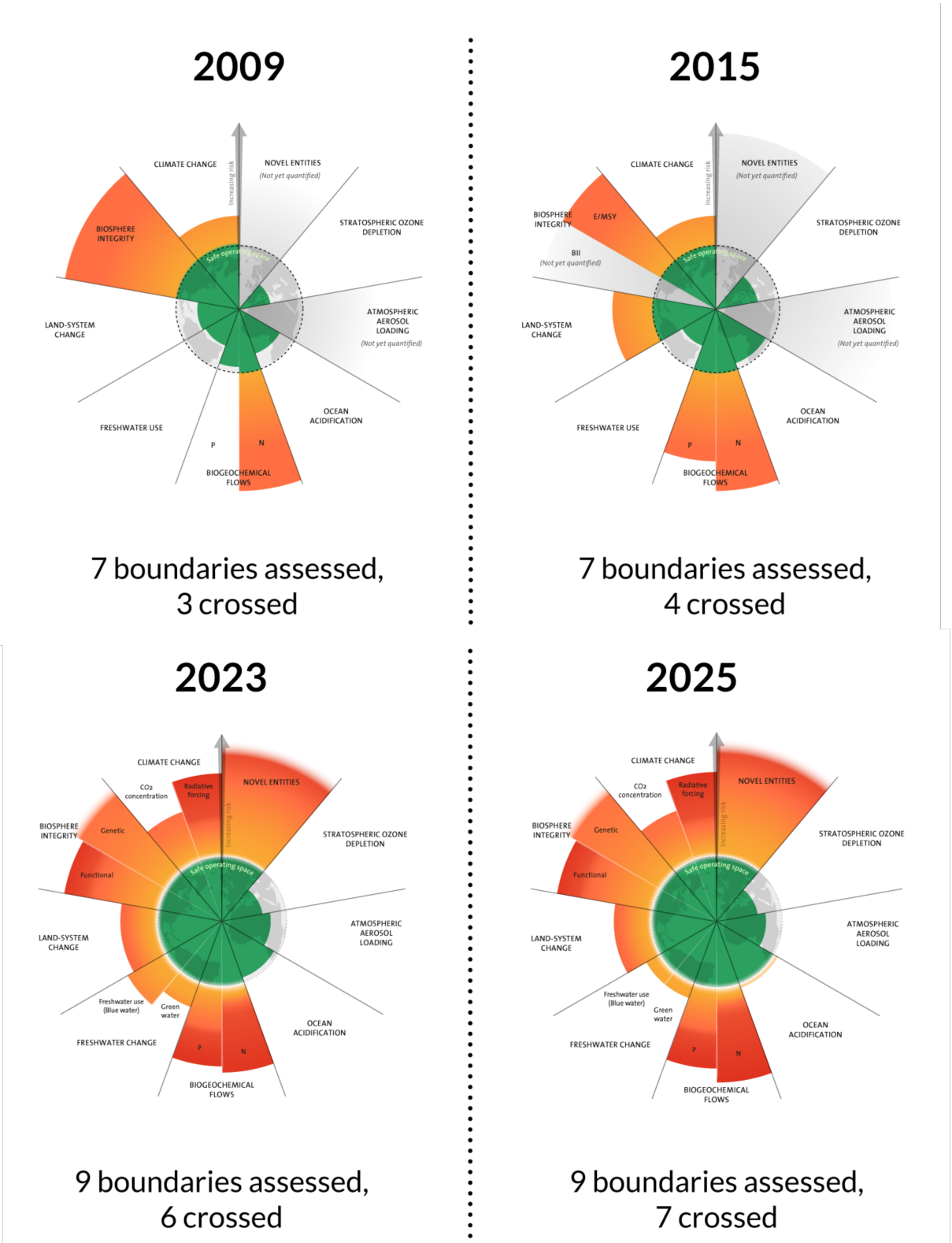


FIGURE 3.1: Planetary Boundaries over time represent the total environmental impact of the world caused by human activity. Planetary boundaries are calculated by identifying the critical control variables for key Earth system processes (such as atmospheric CO_2 concentration for climate change) and determining a safe boundary threshold that lies well before the estimated biophysical tipping point to maintain Holocene-like planetary stability (Stockholm Resilience Centre, 2025).

Recent studies have translated these absolute limits into per-person targets. Several authors conclude that sustainable material footprints must be only a few tonnes per person per year. O'Neill et al. (2018) review analyses recommending a global cap of approximately 50 Gt (7–8 t per person) by mid-century (O'Neill et al., 2018), and UNEP's Resource Panel similarly calls for significant drops in material consumption (U. N. Environment Programme, 2024). Likewise, Lettenmeier et al. (2014) propose an approximately 8 t/capita-yr ceiling for household material footprints in affluent societies (Lettenmeier, Liedtke, and Rohn, 2014). These are drastic cuts, high-income nations generally use tens of tonnes per person now, so converging to approximately 5–10 t/yr implies 70-80% reductions. In fact, Hickel shows that wealthy countries have already exceeded their "fair shares" and would have to reduce consumption roughly five-fold to meet sustainable levels (Hickel et al., 2022). EU-level analyses reinforce this message. The EU's per-person material footprint (14 t in 2024) is well above the safe operating space (European Environment Agency, 2025), and the 8th Environment Action Programme now explicitly mandates binding 2030 targets to bring Europe's material footprints into planetary boundaries (European Environment Agency, 2023). The literature shows overwhelming evidence that only a quantitative "corridor" (a few tonnes per capita per year) is sustainable.

3.1.2 Topic 2: EU's Societal Metabolism

The primary driver of this ecological pressure is caused by the societal metabolism, a term with varying origins and definitions that can be defined as *"the total flow of energy and materials that a society extracts from the environment, transforms through economic activities, and returns as waste and emissions to sustain its structures and functions"* (defined using sources such as (González De Molina and Toledo, 2023)). There is a well-defined correlation between the material throughput required to sustain economies and the subsequent environmental impacts, ranging from biodiversity loss to the disruption of biogeochemical flows (Rockström et al., 2009; O'Neill et al., 2018). The world's societal metabolism constitutes to all environmental impacts, and only reducing this metabolism, can environmental impacts reduce. As we will see in the following sections, decoupling environmental pressures from economic growth is unlikely to happen, the only solution is to reduce the societal metabolism of our societies. Substituting materials with more sustainable alternatives may reduce environmental intensity per unit, but it does not ensure absolute reductions in environmental impact (European Environmental Bureau, 2024; Materials & Consumption Taskforce, The Club of Rome, and Hot or Cool, 2025; Zero Waste Europe, 2024; European Academies Science Advisory Council, 2024). Achieving reduced societal metabolism through policies can be done in a variety of ways. The next sections will cover fields of science and policy that approach this problem from different angles.

3.1.3 Summary of Theme 1

The total environmental impact of the world is exceeding the safe operating space of the planetary boundaries, caused by physical human activity. Physical human activity takes the forms of extraction of resources, production or processing of those materials, transport of materials and products, use of products that might require material throughput, and the waste management of the materials. The core driver behind the total impact of the world is the demand of new materials and products within society, where the rest of human impact comes from use and waste management of materials and products. Unless the demand/inflow of new materials into our economies is not reduced through regulation, the exponential growth of those resources and their corresponding impacts will cause the collapse of the Earth's systems including ecosystems.

3.2 Theme 2: Governance Problem Space

3.2.1 Topic 3: Limits of the Green Growth Paradigm

The current environmental policy paradigm relies on eco-efficiency and technological substitution: improving resource and energy efficiency, and replacing polluting processes and products with "greener" alternatives. Organisations such as the OECD, World Bank and UNEP frame this as achieving "green growth," where GDP can rise while environmental pressures fall through decoupling economic output from resource use and emissions (Hickel and Kallis, 2020; Vadén et al., 2020).

Decoupling can be relative (impacts grow more slowly than GDP) or absolute (impacts fall while GDP grows) (Parrique, Barth, and Briens, 2019; Hickel and Kallis, 2020; Vadén et al., 2020). Relative decoupling has occurred in many high-income economies for CO_2 and some pollutants, aided by efficiency gains, sectoral shifts and environmental regulation (Schandl et al., 2016; Abbas, 2025; Pao and Chen, 2019; Vadén et al., 2020). Scenario modelling also shows that strong carbon prices and resource-efficiency policies could substantially reduce the growth of energy use, material use and emissions while allowing continued GDP growth, at least to mid-century (Schandl et al., 2016; Pao and Chen, 2019).

However, several lines of evidence suggest this strategy is insufficient and too slow to avert ecological breakdown at the global scale. Reviews of historical data and modelled projections find no empirical evidence that global GDP can be absolutely decoupled from aggregate resource use at the scale and speed required for ecological sustainability (Vadén et al., 2020; Hickel and Kallis, 2020; Parrique, Barth, and Briens, 2019). Strong, sustained absolute decoupling of GDP from resource throughput is rare, often confined to specific countries, sectors or pollutants, and frequently reflects offshoring of impacts or crisis-driven contractions rather than structural change (Otero et al., 2020; Vadén et al., 2020; Cerkini, Bajrami, and Bajraktari, 2025). For key planetary boundaries, global impacts have not declined; pressures continue to rise, just more slowly than GDP. A recent assessment finds that from 1995–2019, strong global decoupling has not occurred for any planetary boundary, with stresses increasing though at a lower rate than GDP (Vázquez et al., 2023). Model-based analyses show that, even under optimistic assumptions about technology and policy, absolute decoupling of GDP from environmental pressures is unlikely to be fast enough to keep our societies within planetary boundaries if growth continues at historical rates (Parrique, Barth, and Briens, 2019; Hickel and Kallis, 2020).

Critiques therefore argue that decoupling is at best a measure of ecological efficiency, not of sustainability: even an absolutely decoupled, growing economy can still exceed planetary boundaries if overall throughput remains too high (Vadén et al., 2020; Hickel and Kallis, 2020). From this perspective, a policy paradigm that treats green growth and decoupling as sufficient, risks locking societies into a trajectory where environmental pressures decline too slowly to avoid crossing irreversible tipping points (Vázquez et al., 2023; Hickel and Kallis, 2020; Parrique, Barth, and Briens, 2019).

3.2.2 Topic 4: Attempts at Sustainable Policy Design

Many fields of governance and political science try to find the answers to the problem of societies exceeding planetary boundaries. This section will explore those fields and their solutions to try find a suitable solution to the current gap between planetary boundary science and effective policy mechanisms.

To categorise strands of governance and political science that ask how to steer societal metabolism within ecological limits, it helps to distinguish: (a) methods that analyse biophysical metabolism

itself, and (b) methods that focus on the governance of transformations towards sustainability.

Circular Economy

The circular economy agenda responds to this challenge by seeking to keep the value of products, materials and resources in the economy for as long as possible, reducing virgin material extraction and waste generation. The EU has adopted successive Circular Economy Action Plans and a broad package of regulations to promote repair, reuse, eco-design and higher-quality recycling (European Commission, 2020). However, reviews of policy implementation and material-flow indicators show that recycling still dominates over higher-value strategies, circular material use rates remain modest, and circularity is far from being structurally embedded in production and consumption systems (Ginga, Ongpeng, and Daly, 2020; Malinauskaite, 2024). Studies highlight persistent regulatory gaps, cultural barriers and market failures, and call for stronger standards, fiscal incentives and public procurement to accelerate circular practices, even though, a fully circular economy is not possible in a growing economy (European Environment Agency, 2024).

Post-growth/degrowth/steady-state economics

Post-growth is a governance-oriented strand within sustainability science that asks how to secure wellbeing within planetary boundaries, reduce throughput, and decouple welfare from GDP growth (Kallis et al., 2025; Koch, 2020; Koch and Buch-Hansen, 2021). It encompasses degrowth, Doughnut and wellbeing economics, and steady-state economics (Kallis et al., 2025). Political economy of post-growth, work that fuses critical political economy (e.g. regulation theory, materialist state theory) with growth-critical ecological economics to analyse institutions, state roles and "modes of regulation" compatible with downscaled economic, energy and material throughput (Koch and Buch-Hansen, 2021; Koch, 2020).

Earth System Governance and governance for sustainability

These fields focus on institutions and power at multiple levels. Earth System Governance (ESG) studies "the interrelated system of formal and informal rules and actor-networks" that steer societies in relation to global environmental change, focusing on architectures, agency, allocation, accountability and adaptiveness across problem domains like energy, food and the economy (Patterson et al., 2017; Biermann, 2022). Governance for sustainability/environmental governance is a broader field moving from environmental regulation towards integrated governance of social, economic and ecological systems, explicitly concerned with transformational change rather than incremental fixes (Agrawal et al., 2022).

Sustainability transitions and transformation governance

Here the core question is how to govern regime shifts in socio-technical and socio-ecological systems. Sustainability transitions research examines long-term, non-linear shifts in energy, mobility, food, etc., using notions of regimes, niches and path dependence, with governance approaches such as transition management and transition governance (Loorbach, 2017; Köhler et al., 2019). Governance of transformations towards sustainability integrates several conceptual families: socio-technical transitions, social-ecological systems (adaptive governance), sustainability pathways, transformative adaptation, under a common focus on how governance and politics shape deliberate transformations (Patterson et al., 2017). Modes of governance for transitions: work specifying participatory, collaborative, multi-level, smart and network governance as modes suited to sustainability transitions beyond classic hierarchy/market models (Massuga et al., 2024).

3.2.3 Topic 5: Absence of Adequate Institutional Policy

Combining the literature on the EU's exceeding planetary boundaries from section 3.1, and the assessment of the of current policy mechanisms identified in this section, the conclusion can be drawn that the current policy landscape lacks adequate policy mechanisms that can successfully reduce the EU's environmental footprint below planetary boundaries. The exceeding planetary boundaries identified in section 3.1 and the inadequate results from the attempts at sustainable policy design result in the conclusion that a new form of policy is required. The next section will focus on the solution ingredients for such a policy.

3.3 Theme 3: Policy Solution Ingredients

The conclusion drawn in subsection 3.2.3 require a fundamental rethinking of EU environmental policy. This chapter structures the aspects of policy design together with the problem statement into the argument for an EU resource cap to limit the resource use and resulting environmental impacts of the EU. The start of this section consists of the fundamental principles of governance and later these principles are applied to the EU context. The resource cap-and-trade system as described by (Meysner, Gore, and IEEP, 2022; Kelly, 2024) is identified as a potentially key policy mechanism able to reduce the EU's environmental footprint below planetary boundaries.

3.3.1 Topic 6: Principles of Governance

The first field of policy research, earth system governance, shortly introduced in section 3.2.2, transforms environmental policy as an integral part of general policy design (Biermann, 2022). Biermann argues that environmental policy, understood as a distinct and marginal policy sector, is no longer adequate in the Anthropocene. Biermann shows that traditional environmental policy fails because it is institutionally weak, fragmented, and routinely subordinated to priorities such as economic growth, competitiveness, and security. He critiques dominant narratives such as green growth and market-based instruments, arguing that while they may deliver incremental improvements, they underestimate biophysical limits, rebound effects, and power asymmetries, and therefore cannot stabilize the Earth system at the required speed and scale. As an alternative, Biermann calls for a paradigm shift from "environmental policy" to "Earth-system governance," in which planetary boundaries become binding constraints for all policy domains, environmental objectives are embedded in core state institutions, and principles of intergenerational justice, global equity, and precaution guide decision-making. In this vision, sustainability is no longer a sectoral concern but a foundational condition for governance in the Anthropocene.

Similar to Biermann, Howlett's "From the 'old' to the 'new' policy design: design thinking beyond markets and collaborative governance", describes how new policy design processes are required for systematic change, especially for environmental policy (Howlett, 2014). From "What instrument should we choose?" to "How do multiple instruments work together over time in a specific governance context?". So the long term goal of environmental policy should be, Howlett argues, that modern policy problems require a shift from choosing "better instruments" to consciously designing coherent policy mixes that fit complex governance contexts over time.

3.3.2 Topic 7: Available Policy tools

To fundamentally rethink (climate) policies, the key principles and philosophies of policy need to be studied. When conceptualising a new form of environmental policy, first we need to understand the fundamental policy tools available. These policy tools will be developed in the next chapter. Techniques of regulation are the practical workings of policies and only limited principles exist in policy design. Rogge categorises policy tools into economic instruments, regulation, and information (Rogge and Reichardt, 2016) (Table 2). A more objective approach from Morgan & Yeung is to summarise these options as governance using command, competition, consensus, communication, and code (Morgan and Yeung, 2007) (section 6.3 Techniques of regulation). Command uses traditional "command-and-control" law, where the state sets binding rules (standards, bans, licensing) and backs them with sanctions. Competition uses market mechanisms (liberalisation, privatisation, tradable permits, price signals) so that competitive pressures discipline behaviour. Here, regulators shape the market's rules rather than directly prescribing outcomes. Consensus steers behaviour through negotiated agreements, self-regulation, co-regulation, and stakeholder partnerships. Standards emerge from dialogue and shared commitments rather than unilateral state commands. Communication influences behaviour via information—labelling, disclosure duties, rankings, publicity campaigns, and naming and shaming. The idea is that transparency and reputational pressure prompt regulated actors to change. Code embeds regulation in technical and digital architectures, such as product design, default settings, platforms, and software. Behaviour is constrained or enabled by "built-in" rules (often summarised as "code is law"), so that regulation is carried by design rather than by external legal commands.

3.3.3 Topic 8: EU Governance Style

The theories discussed must now be applied to the European context and European policy styles. This section will cover the European policy principles that must resonate with any future EU policy.

European environmental policy often involves competition governance, the ETS being a clear example as the emission permit prices rise yearly, the adoption of renewable energy sources is the only financial option for companies to compete in the near future (Perthuis and Trotignon, 2014; Vollebergh and Brink, 2020). Also through funding such as the Horizon project, the EU manipulates the market by financially incentivizing sustainable practices (European Commission, 2021). Using competition as governance technique for a future material reduction policy will therefore have the highest probability of success of becoming EU policy.

As competition governance has proven to be a successful policy mechanism, the next section will cover potential environmental policy mechanisms that adopt the competition model.

3.3.4 Summary: Preliminary line of reasoning behind resource law

Acknowledging that the current societal metabolism directly causes environmental issues, the next step in the line of reasoning is that limiting the inflow of materials into our economy is required to reduce environmental pressures. This means reducing our material consumption yearly until our economy stays within planetary boundaries. We have also seen in section 3.2 that current environmental policy is built on the paradigm of economic growth and that solving the environmental issues requires rethinking environmental policy as a whole. Specifically, some form of resource law is required that enforces the required material consumption reductions.

Resource law has been subject to exploratory research by think tanks and other research institutes (Kelly, 2024; OVAM and institute, 2024; Zero Waste Europe, 2024; Meysner, Gore, and IEEP, 2022). The design of the resource law has not been discussed much, but a cap-and-trade system that limits the import and extraction of materials to the EU has seen some detailed discussion (Kelly, 2024). Exploring the possibilities and obstacles of this proposed policy will require specifying further design choices of the policy in the European context. Designing this policy alongside an exemplary material flow subject to the policy, will further uncover practical and ethical considerations for this policy. The next section will cover the full line of reasoning for adopting a resource cap to limit the EU's environmental footprint below planetary bounadaries.

3.4 Topic 9: EU Material Cap-and-trade System, Towards European Environmental Policy within Planetary Boundaries

Starting with environmental problem from section 3.1, the debunking of the current decoupling paradigm from section section 3.2, and inadequate alternatives from section **??** and subsection 3.2.3, we have identified the ingredients for a policy solution in section 3.3, and identified the EU policy style, combining those we now have identified that a resource cap on material input for the EU is a promising policy proposal.

This is in line with a growing body of literature that calls for macro-scale instruments capable of regulating material use at the level of entire economies. The Institute for European Environmental Policy (IEEP) paper "Towards resource consumption within planetary boundaries" envisions future environmental policy as explicitly centred on absolute reductions in resource use, rather than continued reliance on efficiency gains, recycling, or relative decoupling from GDP (Meysner, Gore, and IEEP, 2022). The report argues that environmental policy must move beyond productivity-based and circularity indicators and instead adopt science-based, binding material footprint reduction targets that align EU consumption with planetary boundaries. Policy is framed as strongly demand-side oriented, combining binding targets with product regulation, sufficiency measures, and systemic interventions to prevent overproduction and overconsumption. In this vision, environmental policy functions as an overarching framework that steers industrial, energy, trade, and consumer policy simultaneously, prioritising well-being, equity, strategic autonomy, and environmental limits over economic growth as the primary objective of governance. A resource cap is an essential policy tool needed to achieve a sustainable future. Similar arguments are presented by the European Environmental Agency, European Environmental Bureau and Zero waste Europe (European Environmental Bureau, 2024; Zero Waste Europe, 2024; European Environment Agency, 2024; Kelly, 2024; Ekins et al., 2014).

3.4.1 Key Design Aspects for a Resource Cap-and-trade System

The research gap identified by Kelly is the design of a resource cap as an essential step to advance the scientific discussion on resource caps (Kelly, 2024). This research aims to partly fill this gap in the following way. Two design aspects of the "resource cap" will be discussed in the next chapter, each considering the main design options and their implications. In this section, the two design aspects that will be discussed are chosen. The following arguments are the justification for the choice of design elements.

The concept of cap-and-trade systems originates from 'depletion quota's' used to limit the extraction of renewable and non-renewable resources that were mainly identified important for the long term sustainable extraction of those resources (Daly, 1974, p. 163). Fishery is an excellent example as the uncontrolled extraction of fish can cause the depletion of the source of fish

as a extractable resource (Gorman and Solomon, 2002). The contemporary form of depletion quota's are cap-and-trade system such as the EU ETS, aimed at capping environmental impacts in a given region (Svendsen, 2003).

As identified as a critical research gap in the scientific literature on resource caps, the main aspect of a resource cap-and-trade system need to be identified for their conceptual development (Kelly, 2024, p. 10). The design aspects identified critical design choices in this section for the conceptual design of an EU resource cap are the regulated metric that is capped, and the permit price calculation.

The regulated metric determines what unit is capped in the regulation, for fish quota's the regulated metric is fish, and for the ETS the regulated metric is tons of $CO_2 - equivalent$. As defined in List of Definitions, a regulated metric is defined as: *"A regulated metric is the standardised unit of measurement defined by a regulatory framework to quantify and monitor the specific activity being governed. It serves as the legal and accounting basis for compliance, determining exactly what units must be tracked and reported by a regulatory system."* As the name cap-and-trade system suggests, the regulated metric (the entity that is capped) is the first design aspect to be determined. Other aspects of the cap-and-trade system rely on the design choice of the regulated metric. For example, the height of the cap relies on what the regulation caps, the allocation of the cap relies on what is capped as a product cap must be allocated differently than a mass-based cap. The regulated metric of the cap will thus be the first conceptual design subject of this research.

The regulated metric fundamentally determines the functioning of the regulation. Similar to taxes, a system changes drastically when taxing different entities. A tax on income results in a very different society than a tax on wealth. Therefore, a well defined regulated metric is essential to accomplish the right environmental and societal outcome. In this research, a few design options are considered holistically, but not worked out into concrete policy. For example, the height of the cap is discussed briefly including factors that might influence it. The "design" of the regulated metric merely touches on different design options and their societal and environmental impact.

For the second design aspect, the permit price, the following factors influenced the choice for conceptual design. Unlike a depletion quota for fish or other local resource, and unlike contemporary emission cap-and-trade systems, a resource law must govern a variety of resources within the same regulation. This can be seen as a main fundamental differences with conventional cap-and-trade systems. For the advancement of the scientific debate on resource caps requires consideration of how different resources compare and relate within the regulation.

Other aspects of the conceptual design of the regulation will be briefly discussed as well. The next section covers the criteria that the conceptual design will be tested on.

Jumping ahead to the results that will be presented in chapter 4, I now introduce the resulting Material Allowance Trading Scheme. Although other options are explored within this report, a mass-based option was elaborated most. The system caps the mass of the materials from imported goods and extracted materials within the EU. The environmental impact of those materials are not directly capped, but as all materials are capped individually, the environmental impact of the cumulative materials is capped indirectly, meaning, since the total material footprint of the EU is capped, the environmental footprint is capped as well. This is based on the assumption that there is a linear relationship between material footprint and environmental footprint, as long as the distribution of different materials remains the same, although the distribution will not be the same and this must be accounted for by calculating the environmental impact. Directly capping environmental impact was found less feasible, as the environmental

impact cannot be measured like mass can be measured. A calculation of the impacts is required, which is less transparent for importers than mass measurements. The front end of the regulation uses mass as measurable indicator, and in the back end, the environmental impacts are calculated and governed.

3.4.2 Resource Cap Conceptual Design Criteria

The literature concerning material cap-and-trade system mentioned in the previous section has societal and economic implications that require attention in the design phase of the regulation (Kelly, 2024; Meysner, Gore, and IEEP, 2022). The following lists is compiled as criteria/requirements for the design of such policy.

a) yearly reductions in material consumption that steer the EU's societal metabolism and the resulting environmental impacts below planetary boundaries, while:

b) maintaining a sufficient level of societal metabolism required for the material needs of the EU population,

c) maintaining the economic and social wellbeing of the EU population,

d) restoring a flourishing biosphere within and outside the EU,

e) maintaining the right to develop: maintaining individual, corporate, and EU-wide autonomy, wellbeing and development potential,

f) ensuring a well-functioning public management with democratic decision-making (stakeholder representation), implementation term, access to justice, and communication of the policy towards citizens.

These criteria apply to the design of the MATS regulation in chapter 4, and will be evaluated in chapter 5.

3.5 Summary

In this chapter we have identified the environmental issues and their growing urgency, we have seen the shortcomings of current policies, and we have argued the need for a resource cap in order to reduce the EU's environmental footprint below planetary boundaries. The societal metabolism of the EU and other "developed" regions is the cause of the overshoot of planetary boundaries. Only by reducing the total inflow of materials into those societies, can the environmental impacts of those regions drop below planetary boundaries.

The key design aspects identified in subsection 3.4.1 are the regulated metric of the cap and the permit price calculation method for the resource cap-and-trade system. The next chapter will cover the initial design of these key design aspects and the discussion of other design aspects of the cap-and-trade system. The resulting concept regulation will be subject to discussion in chapter 5.

Chapter 4

Material Cap-and-Trade Regulation Design

In the report outline from chapter 1, the policy design in this chapter was announced as the second part of the results of this thesis. In this chapter, the conceptual design aspects identified in subsection 3.4.1 will be modelled, according to te modelling method described in section 2.2.

As we have learned from chapter 3, a regulatory framework is required that limits the material footprint of the EU. A cap-and-trade system on imported goods and materials and extracted materials within the EU is proposed by literature as a possible regulatory framework. Designing such regulation requires the consideration of multiple design choices. This chapter aims to address these design choices, present their opportunities and barriers, and present the results as a proposed regulation that can effectively steer the EU's economy below planetary boundaries.

As described in section 2.2, the method used in this chapter is derived from the policy design method. Figure 4.1 visualises the policy design method developed by Howlett (Howlett, 2023). As described in section 2.2, the agenda-setting and conceptual policy formulation will be the focus of this chapter.

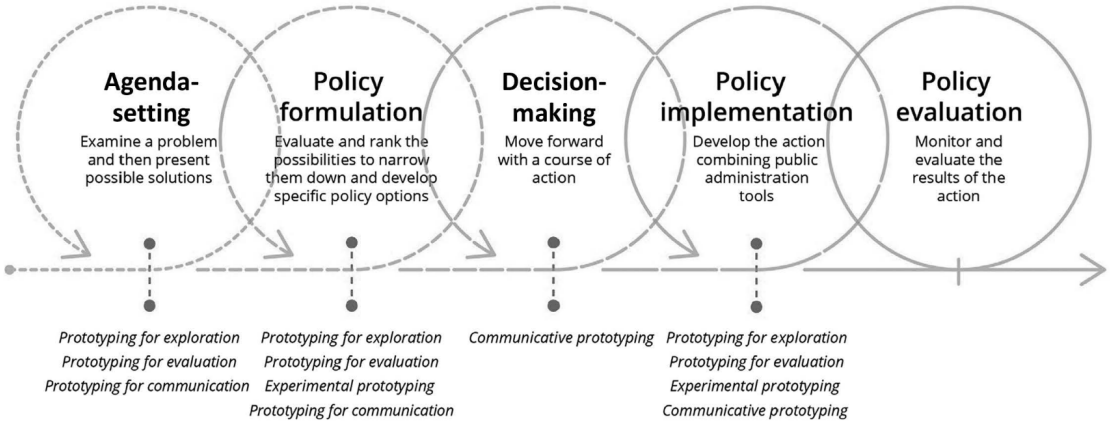


FIGURE 4.1: Policy Design Cycle (Howlett, 2023)

First, section 4.1 will cover the design choices concerning the cap. Then the design choices regarding permit allocation and trading are explored in section 4.2. section 4.3 describes the

proposed regulation design as a result from the previous design choices. Finally, section 4.5 covers the summary of this chapter.

4.1 Material Cap-and-Trade Regulation Cap Design

Limiting material consumption requires a well defined cap that solves the environmental impacts of the EU at the core. In this section, the design choices of the MATS regulated metric will be discussed and opportunities and barriers of the design choices will be explored.

4.1.1 The Regulated Metric

Limiting material consumption using the MATS regulation requires a well-defined regulated metric. As defined in List of Definitions, a regulated metric is defined as: *"A regulated metric is the standardised unit of measurement defined by a regulatory framework to quantify and monitor the specific activity being governed. It serves as the legal and accounting basis for compliance, determining exactly what units must be tracked and reported by a regulatory system."* The regulated metric is not the same as the cap height. The regulated metric is the unit that is capped, and the cap height is the amount of permits available in that regulated metric (unit). This section covers 4 possible options for the regulated metric, environmental-impact based metric, product-based metric, monetary-based metric, and mass-based metric.

Environmental Impact Cap as Regulated Metric

Capping environmental impact has certain advantages over the other options. As the goal of the policy is to reduce environmental impacts, this option seems obvious. For this to work, all imported goods must be carrying an environmental impact passport. Calculating the environmental impacts must be done using LCA methods where the impact throughout the good's life is calculated. The good's life cycle impact can be calculated for different parts of the life cycle. The total impact of a product is calculated using cradle to cradle (in case of circular products), or cradle to waste (in case of linear products). As the products at the European border are halfway on their life cycle, an equivalent life cycle scope must be used. Cradle to gate represents the life cycle of a product from extraction of raw materials to the end of the production. As the MATS policy is applicable to raw materials, finished materials, products and more, different life cycle approaches would need to be used depending on the imported good.

The total cap of an environmental impact based cap-and-trade system can be either a single metric, or 16 separate caps for all impact categories. Using a single metric will distort the importance of different impact categories as 1 permit of $CO-2$-equivalent will contribute equally as 1 permit of SO_2-equivalent. This can be solved by differentiating the allowance of 1 permit for different impact categories. For example, 500 kg of CO_2-equivalent emissions, and 200 kg of SO_2-equivalent emissions both require 1 permit.

Methods for an environmental impact cap as regulated metric
Different methods are available to determine the environmental impact cap. Setting the cap on current environmental impact levels is one option, where the environmental impact of all current imports need to be calculated by either the importer, producer, or the European authorities. Methods for reducing the cap to planetary boundaries will be studied in subsection 4.1.3.

Data required for an environmental impact cap as regulated metric
The data needed for a environmental impact based cap is the data available of the imported good's environmental impact. The data to calculate a product or material's impact can be

found in LCA databases. Ecoinvent is the largest LCA database at the moment with data of 26,000 processes (Ecoinvent, 2026). When calculating the environmental impact of a material like steel, Ecoinvent has multiple data points for the production of steel differentiating multiple production methods and some geographic locations. For an imported product, it must be determined how and where the product was made. Data on the supply chain for its materials must be determined to accurately calculate the product's environmental impact using LCA. This data is used to determine the permits required for the import of the product. The cap for the MATS policy will consist of the 16 impact categories with each a total unit-equivalent. For example, land use is one of the impact with $kg\ SO_2 - equivalent$ as unit, so the cap will be set on an X amount of total $kg\ SO_2 - equivalent$ per year to be imported and extracted within the EU.

Results from an environmental impact cap as regulated metric
Choosing total environmental impact as regulated metric results in a system where the cap directly represents the total environmental impact of imported and extracted goods in the EU. The resulting environmental impact reductions can be seen directly in the regulated unit, but calculating the environmental impacts for all products and materials is subject to errors and therefore, the resulting environmental improvements are subject to error. The system is easily subject to scrutiny because of these errors.

Design Option Example: Environmental Impact Cap

1 Ton of Iron Ore: Instead of Surrendering a 1 Ton permit, the importer surrenders "Impact Units" (e.g., kg SO_2-equivalent and CO_2-equivalent).

If extracting 1 ton of iron ore causes 500 kg of CO_2-equivalent emissions, 500 permits need to be submitted. If the extraction of 1 ton of iron ore also causes 200 kg of SO_2-equivalent emissions, 200 permits have to be submitted on top of the previous permit. Alternatively, different impact categories are weighted differently changing the required permits required per impact category.

As an example, for each impact category, 1 ton of the impact caused, requires 1 permit for that impact category. If extracting 1 ton of ore causes 2 tons of SO_2-equivalent emissions, the importer uses 2 SO_2-equivalent permits from their total annual impact allowance.

1 Ton of Steel in a Car: This requires a detailed Life Cycle Assessment (LCA) passport for the car. Because the car has gone through energy-intensive manufacturing, its 1 ton of steel might represent 2,000 units of impact—significantly more than the raw ore.

Practicality: This is the most accurate for the environment but the most difficult to implement, as the impacts of the imported materials have to be calculated individually which might not be transparent and requires the manual validation of the calculated impacts for all imported goods.

Product Cap as Regulated Metric

Setting the regulated metric on the number of products is another option. Though, material imports and extraction cannot be measured with this regulated metric. This option will not be further explored in this report.

Design Option Example: Product Cap

This metric sets a limit on the quantity of specific items.

1 Ton of Iron Ore: This metric generally fails here. It is impossible to set a "product quota" for a pile of dirt/ore unless it is bagged as a specific consumer product.

1 Ton of Steel in a Car: The regulator sets a limit on the number of cars allowed to enter the EU (e.g., 2 million cars per year).

Practicality: While simple, it is highly ineffective for a reducing environmental impacts because it ignores the raw material imports and does not account for the weight or material type of the car.

Monetary Cap as Regulated Metric

The current regulated metric in international trade negotiations is monetary, such as the EU-Mercosur agreement (European Commission, 2026a). Implementing a monetary regulated metric in the cap-and-trade regulation would limit the value of different types of materials entering the EU economy. As the value of goods is not related to their environmental impact (Malinauskaite, 2024), this system would not serve the purpose of accurately limiting the environmental impacts of imports. This method will thus not be considered in this thesis.

Design Option Example: Monetary Cap

This metric limits the total financial value of material flows.

1 Ton of Iron Ore: If iron ore is $100/ton and there is a $1 billion cap on ore imports, you use $100 of that cap.

1 Ton of Steel in a Car: A luxury car containing 1 ton of steel might cost $100,000, while a basic car costs $20,000. Under a monetary cap, the luxury car "consumes" 5x more of the cap, even if they use the same amount of steel.

Practicality: This is the current standard for many trade quotas but is deemed inaccurate for representing environmental impacts. Only when externalised costs are internalised for all imports, such a system could work.

Mass-based Cap as Regulated Metric

Limiting the mass of materials and the materials within products is another alternative for the MATS regulated metric. For imported goods and extracted materials, the mass will count towards a European cap of the materials in question. Although it does not directly reflect the hidden impacts of the material, a mass-based system directly addresses the scale of material use, which is the fundamental driver of most environmental pressures. By capping total material throughput, MATS ensures that absolute resource consumption decreases. Figure 4.2 shows the potential reductions in raw material equivalent material footprint per capita under a material cap-and-trade system. The projected material consumption is subject to the material cap-and-trade system where at first 0% reductions are enforced, and the yearly percentual decrease grows exponentially to 5% per year in 2050. After 2050, the reduction becomes 0% again,

meaning a constant cap on imports at approximately 8 tonnes per capita.

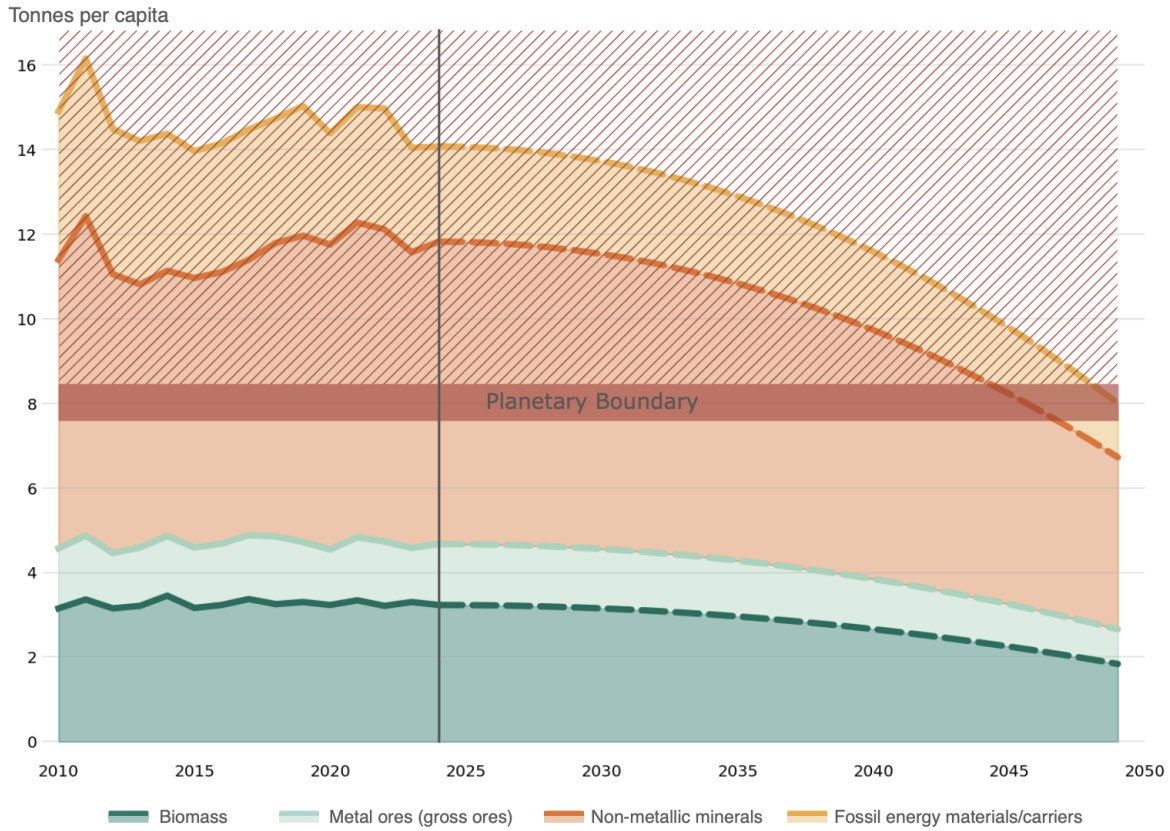


FIGURE 4.2: EU material reduction under a mass-based cap-and-trade system. EU Material Footprint, expressed in tonnes of raw material equivalent per capita (stacked). 2010-2024 data from (European Environment Agency, 2025)

Methods for a mass-based cap as regulated metric

The first method to establish a mass-based cap consists of multiple aspects influencing the cap. The current use of materials is important to consider when implementing the MATS regulation. Especially during the initial phase of the regulation implementation, a 'learn by doing' approach gives time to correct faults in the system. Implementing the regulation at a cautious pace means aligning the cap levels with current consumption levels. Once the regulation performs reliably, planetary boundary goals can guide the cap setting. Reduction targets can first follow an adoption phase where lower material reduction targets are realised. As industries adopt to the lower material consumption targets, an acceleration phase can realise yearly material reductions that reduce the EU's material footprint towards planetary boundaries quickly.

Another method is to calculate the weighted impact of all materials and set the cap according to the material's impact. For materials with a high environmental impact, the cap will be set low and vice versa. The regulated metric will be material mass, but the cap will be determined using LCA normalisation and weighting. The drawback of this method is the one-sided focus on environmental impact. Societal considerations cannot be implemented into this method. Another drawback is that it does not account for the current use of all materials. Materials with high environmental impacts will be subject to a low cap and if that cap is one tenth of the current use of that material, the regulation might inflict damage on the industries dependent on that material. Accounting for this side-effect with factors that represent the current use of the material result in a method similar to the mass-based method.

Data required for a mass-based cap as regulated metric
The data required for a mass-based cap consists of current material import data, and planetary boundary data. Eurostat tracks import and export data for approximately 10,000 product and material flows, on the website Easy Comext (Eurostat, 2026). The import of all material flows from outside the EU will be subject to the cap. The current flows of material can be converted to material caps where different lands of origin, and different flows with the same chemical compound fall under the same cap. For example, flat-rolled steel from China which has the same chemical composition as tube steel from India can fall under the same cap. Reducing the amount of product flows that are in the regulation creates broader material caps, gives importers and industries more options in the selection of their suppliers. The Combined Nomenclature (CN) system processes final product not with their material content, but as the amount of kg of the final product (European Commission, 2026b). Therefore, another system is required to determine the material contents of those products. A design choice is required on the level of embedded impacts and materials required to produce a certain product. The choice lies between calculating the material content of a product, or calculate the embedded impacts of the products from its life cycle up to that point.

The planetary boundaries framework needs to be converted to material footprint boundaries, where some materials with higher environmental impact contribute more towards the planetary boundary than others. This means that the planetary boundary is approximately 8 tonnes per capita, but can be higher or lower depending on the distribution of materials. As long as the total material import/footprint of the EU is larger that the EU's planetary boundary, material reductions are required.

Results from a mass-based cap as regulated metric
Based on a selection of the criteria, environmental impact progress and practicality, the following results on the design choice for regulated metric are presented. The mass-based cap results in a system where the mass of imported materials and goods and extracted materials is limited to a certain cap per material per year. All imported and extracted materials fall under this regulation to avoid leakage of material flows through non-regulated material imports.

Impact-based indicators, such as life-cycle environmental metrics, require subjective weighting of diverse effects and rely on complex models, and measuring the economy-wide progress of the regulation is harder with indirect measurements. By contrast, the mass of materials is measurable and transparent, making it easier to monitor, enforce, and link to planetary boundary targets, such as the less than or equal to 8 t/capita material footprint goal by 2050. Moreover, focusing on absolute material flows prevents burden shifting, for instance, by capping low volume with high environmental impact material flows individually, those mass flows can be controlled. With other impact-based metrics, high impact material flows can squeeze out lower impact material flows as the cap tightens.

The primary critique of a mass-based system is that it may obscure materials with disproportionately high environmental impacts per kilogram such as critical metals compared to bulk materials with lower impact intensity, such as sand or gravel. To address this limitation, a material cap-and-trade system shall not apply a uniform cap to all materials. Instead, each material is assigned its own cap, price, and reduction trajectory, reflecting both its quantitative contribution to total throughput and its relative environmental burden. In this way, the system retains the transparency, objectivity, and fairness of a mass-based indicator while integrating environmental differentiation into the market mechanism. This design ensures that all materials contribute to the overarching goal of reducing Europe's total material use within planetary boundaries, without reproducing the impact bias inherent in traditional, single-focus environmental policies.

Further design choices of the mass-based system will be explored in the rest of this report.

Design Option Example: Mass-based Cap

This metric governs the physical weight of materials.

1 Ton of Iron Ore: The importer surrenders permits for exactly 1,000 kg of iron ore. The "price" per kg is weighted based on the environmental impact of iron ore extraction and processing.

1 Ton of Steel in a Car: The car importer must declare the material composition of the vehicle. For the steel portion, they surrender permits for 1,000 kg of steel. The permit price for this steel is higher than for raw ore because it includes the "embedded" impacts of refining and manufacturing up to the EU border.

Practicality: It directly addresses the "scale" of material use, which is the primary driver of environmental pressure.

4.1.2 The material consumption indicator for cap setting

If the mass-based approach is used as the regulated metric in the MATS policy, the material consumption indicator reflects the focus of the regulation. This section will cover the selection of the indicator, and therefore the implicit focus of the regulation.

The material consumption of a society can be calculated using different methods. The methods differ in what material flows they include in the calculation which consist of a selection of the following; material extraction within the region, extracted raw materials imported to the region, exported raw materials from the region, imported products, exported products and used materials within the region. The methods considered in this thesis will be Material Footprint (MF) (European Environment Agency, 2025), Domestic Material Consumption (DMC) (OECD, 2025) or Direct Material Input (DMI) (Eurostat, 2025).

DMI measures the total amount of materials directly extracted or imported into a country for use in its economy, without accounting for exports. DMC builds on this by subtracting exports from the sum of domestic extraction and imports, reflecting the physical resources actually consumed within the country. The MF, in contrast, takes a consumption-based perspective, capturing the total amount of raw materials extracted globally to satisfy a country's final consumption, including all upstream materials embedded in imported goods. The MF is often calculated using raw material consumption (RMC), to measure the total amount of raw materials required globally to satisfy the final demand of an EU country. It measures the total amount of primary raw materials extracted worldwide to produce the goods and services consumed by residents of a country. The key difference is that DMI and DMC focus on territorial flows of materials, what physically enters or remains in a country, whereas MF accounts for global resource use linked to consumption, providing a more comprehensive picture of a country's environmental responsibility. In short, DMI counts imports as they enter the country, DMC subtracts exports, MF also includes all hidden upstream materials.

Two perspectives on material input

Calculating the material footprint of a region can be done in multiple ways, each with a different scope. First, one can measure the total imports and extraction of that region with a rough division of metals, non-metalic minerals, fossil materials and biomass. The total mass that is

measures is a relatively accurate indication of the regions material input, however, the contents of that material input is not accurately measured that way. Meaning, the individual material types and their input is not considered in this method. Examples of this method are DMI, MF or DMC, discussed in the previous section.

Alternatively, tracking specific materials can be done to estimate the specific material input of that material. The drawback here is that not all of that material import will be recorded using a homogeneous database. This gives a more accurate indicator of that materials input, but scaling this method to all materials is infeasible to accurately measure the total material input into the region.

For this policy, the first method is suitable for keeping track of the overall progress of the policy, aiming at a reduction of the total material input of the EU by X percent. To calculate the import of our exemplary material copper, the second perspective is required. section 4.1.1 describes the methods and data required for this approach. The rest of this thesis will focus more on the second perspective, as the material specific perspective is required for calculating the material's cap.

Design Option Example: Material Indicator

1 Ton of Iron Ore: For raw materials, the transition from data to regulation is straightforward because the material flow and the product are identical.

- Identification: The shipment is logged under its specific CN code for "iron ore."
- Cap Setting: The regulator looks at the total tonnage of all iron ore imports recorded in Easy Comext (e.g., 100 million tons) and sets the annual cap accordingly.
- Practical Counting: When importing 1 ton, Easy Comext records exactly 1 ton of inflow. One must surrender 1 permit (for 1 ton = 1 permit) of "Iron Ore Permits" from the available EU-wide cap.
- Consolidation: Different flows with the same chemical composition (e.g., iron ore from Brazil or Australia) are grouped under the same cap to allow for market flexibility.

1 Ton of Steel in a Car: The steel contents within a car must first be calculated. If the steel content of an imported car is 1 ton, 1 permit for finished steel is required to be submitted.

Product material content

The MATS permit price will apply to raw materials, as well as final products consisting of multiple materials. Determining the material content of that product is thus required to determine the permit price of that product. A product passport is required that shows the material content of a product that is imported.

For example, imported goods containing copper will count towards the total cap on copper. This would entail imports, extraction and imported products. Trade codes of products must have an additional material content table that states the weight of the materials in the product.

4.1.3 The Cap Sizes and Reduction Goal

The size of the caps for materials can be determined using a variety of methods. For a mass-based cap-and-trade system, the cap size represents how many 1-Ton permits will be available

for each material per year. This section briefly covers the design considerations of the cap sizes. This topic will be discussed briefly, and due to time constraints, the process of determining the cap falls outside the scope of this report.

The following non-scientific determined list of requirements can have influence on the process to establish the height of the material caps:

- The current use of the material should represent the cap at introduction of the regulation
- The (expected) trajectory of the material use in the future must be reflected in the projection of the future cap size
- The environmental impact of the material must be evaluated compared to similar or replaceable materials (not elaborated further in this research, see next paragraph)
- The replaceability of the material must be determined, as irreplaceable materials that serve a key function in society should be subject to more lenient material reductions.

The setting of the height of the material caps are a function of the previous points mentioned. However, the weights of the points mentioned will not be considered in this research. The setting of the height of the material caps is a complex political debate since it will have significant impact on society and industries. For example, the weight of the environmental impact of materials on the material cap cannot dictate the height of the caps. This will result in the largest economic impacts on industries as the caps will be mismatched with the current use of materials and the cut-off of some materials will greatly impact the industries dependent on that material. Therefore, to prevent the growth of environmental impacts, the current use of all materials must be set as cap initially, and later, an equal reduction for all materials is necessary to reduce the total environmental impact of the EU.

Based on the previous points, the cap size can be determined in such a way that the requirements from subsection 3.4.2 will be respected. For example, the design option example illustrated below shows how an ill-defined cap size method can distort the values of effective, value-driven policy.

Design Option Example: Environmental Impacts-focused Cap Reduction Goal

A method to determine the cap size of the individual materials is by environmental impact of the materials. Each material has an environmental impact, and the difference of the environmental impacts between materials can guide the process of determining the cap of the materials. A direct implementation of the environmental impacts to the cap heights is highly impractical, as the material needs can be significantly higher or lower than the determined cap height. If the cap of the material with the highest impact corresponds to the lowest cap, and that material is widely used resulting in a cap one 100th of the current use of that material, production of all industries reliant on that material becomes infeasible.

How the caps can be determined must be a combination of the requirements mentioned above. The goal of the policy is to reduce the environmental footprint of the EU by reducing the resource use (DMI), as defined in subsection 4.1.2. A homogeneous reduction of x% per year for all materials can be an effective starting point, from which exemptions can be made for materials that require more or less yearly reductions. Another design option example is given below.

Design Option Example: Industry-focused Cap Reduction Goal

Adoption Phase: Initially, the cap for iron ore would likely be set close to current EU consumption levels to allow industries to adapt.

Acceleration Phase: The cap is then reduced yearly toward "planetary boundary" targets.

1 Ton Example: If the EU decides that the sustainable "planetary boundary" for iron ore is 50 million tons but currently uses 100 million, they might set a cap that first reduces by 0-1% per year, and later 5% every year until the 50 million ton target is reached.

As can be seen from the design option examples, setting the cap size using different methods can have severe consequences for industries. Further research on methods to determine the caps in line with the criteria for efficient and effective policy is required.

4.1.4 Reflection of Literature on Regulated Metric

Within the literature in chapter 3, we have established that for the sufficient reductions in environmental footprint of the EU, a reduction of the EU's societal metabolism is needed. A resource cap might be a solution and this research discovers possible design choices for such a regulation. Although the MATS is a step in the direction of a sufficient regulation, some important questions remain unanswered. Concerning the regulated metric design options, the discovered options need to be tested whether compatible with the paradigm shift required for environmental policy as described in the literature review. For example, the environmental impact based regulated metric originates from the efficiency-centred policy paradigm, so further research must establish whether this approach is compatible with the new policy paradigm or not. The concept of a resource cap is an extension of post-growth literature and the conceptual design of the MATS regulation must be tested on the principles of post-growth. By iterating the translation of post-growth principles to conceptual policy, a future, more concrete vision of the post-growth paradigm can be established.

4.2 Material Cap-and-Trade Regulation Permit Design

This section covers the design aspects of the regulation permit. For a cap-and-trade system, the permits are the entities that are bought, used and traded. Companies that import or extract materials into the EU require purchasing permits. The supply of permits for a given type of material is defined by the cap of that material. If all permits are sold for a given material, no more import or extraction of that material is allowed that year.

The method to determine the price of the permits can be influenced by multiple factors. As in line with EU environmental policy such as the ETS, permits for processes and products with high environmental impacts are taxed more than processes and products with lower environmental impacts (Vollebergh and Brink, 2020). For the trading mechanism of the material cap-and-trade system, this philosophy can be transferred and materials with higher environmental impacts can have higher permit prices than materials with lower environmental impact. Although other options exist, such as a flat rate or monetary value-based permit prices, the environmental impact-based permit price will be explored further in this research. For the eventual method determining permit prices, a combination of environmental impact, monetary value, and scaling the different prices further or closer to each other can be desirable for aligning taxes with fundamental tax theories. However, as those theories fall outside the scope of this report, the environmental impact-based permit prices will be discussed in this report.

Although the cap is expressed in physical mass, the trading mechanism introduces an environmental weighting factor that converts the mass into an environmental price per kilogram. This factor reflects the aggregated environmental impact of each material, derived from Life Cycle Impact Assessment (LCIA) weighting methods (De Bruijn et al., 2002, p. 93)(Itsubo, 2015, p. 301). Materials with higher life-cycle environmental impacts would therefore have higher permit prices. This design ensures that even if the overall cap is set in physical mass, the market incentives for reduction favour materials that cause the least environmental damage.

The combination of physical caps and impact-based trading allows the policy to maintain both objectivity and focus on environmental impacts. The mass-based cap provides a clear and easily measurable indicator that is transparent, verifiable, and universally understood. This addresses one of the persistent challenges of LCIA-based policymaking: weighting methods inevitably involve subjective choices and normative assumptions. By using mass as the primary cap metric, the policy maintains an "absolute truth" reference point, while using environmental weighting as a secondary layer to guide the relative value and exchange of permits.

As stated in subsection 1.2.1, the ultimate objective of the policy is to reduce the overall environmental impact of Europe's material consumption. The most reliable way to achieve this is by ensuring reductions across all material categories. If a weighted impact score were used as the primary indicator, the effectiveness of the regulation would depend on the specific weighting method applied, a method that inevitably reflects subjective choices about which environmental impacts are prioritised over others, and can therefore always be scrutinised.

One key design principle is to prevent harmful material substitution. Previous research has shown that dematerialisation policies based solely on mass reduction can lead to counterproductive outcomes, such as the replacement of heavy, low-impact materials (e.g., steel) with lightweight, high-impact ones (e.g., aluminium or composites) (Voet, Oers, and Nikolic, 2004). To avoid this, the proposed system limits substitution opportunities by assigning separate caps to each material type. This enables cross-material trading using a unit-of-trade that incorporates the difference in environmental impact of the traded materials. This reduces the risk of environmental burden shifting and ensures that reductions in material use translate into real impact reductions rather than changes in composition.

Over time, as the cap tightens, companies will face increasing costs for material use, particularly for those materials with high impact-weighting factors. This creates a market-driven incentive for material efficiency and circular business models such as reuse, repair, and recycling. By attaching an environmental penalty to each kilogram of material, the policy translates environmental pressures into an economic signal, aligning private decision-making with societal sustainability goals.

4.2.1 Normalisation and Weighting

Determining a suitable normalisation and weighting method will be the focus of this chapter. First, existing methods will be identified. Then, the requirements from the last chapter will guide the selection process of the best normalisation and weighting method.

The most suitable normalisation and weighting method will be subject to further research. An exemplary application of the MATS policy will be used to demonstrate the mathematical workings of the method.

The price of MATS permits are not only determined by the weighted score of each material. How the method deals with the unaccounted impacts will be discussed as well. Other factors include existing regulations such as import duties.

Normalisation Methodologies

Normalisation is the step in a life cycle analysis where the results from the impact assessment are normalised for a given reference (Laurent and Hauschild, 2015). After the initial "characterisation" step, results are often expressed in varied units (e.g., mass of CO_2 for climate change vs. mass of $NMVOC$ for ozone depletion), making direct comparison difficult.

Normalisation works by dividing each impact score by a reference value, such as the total annual environmental impact of a specific region or a single person (per capita). This places all results on a common scale, facilitating their interpretation and preparing for weighting.

There are two primary approaches, internal normalisation where the reference is a value from within the study itself, such as the maximum score or a baseline scenario, and external normalisation where the reference is independent of the study, typically representing the total annual activities of a nation, region, or the entire world (Laurent and Hauschild, 2015). Internal normalisation is not compatible with the MATS regulation, as this does not result in a generic base-level that can be used in weighting. Therefore, external normalisation options can only be considered. This approach uses a reference system independent of the study, typically representing a much larger scale, such as a company, a nation, or the world. There are several sub-options for external normalisation.

Production-based normalisation focuses on environmental flows occurring within specific geographical boundaries (e.g., all emissions produced within the EU). Consumption-based normalisation focuses on the environmental flows required to support the consumption activities of the reference group (e.g., all impacts of products consumed by EU citizens, regardless of where they were produced).

Laurent notes that while internal normalisation was common in the 1990s, the development of external normalisation has made it the preferred method because it can address both result interpretation and "sanity checks" more effectively (Laurent and Hauschild, 2015). For the purpose of normalising the LCA results for weighting within the price calculation step of the MATS regulation, a consumption-based normalisation approach on EU or global scale are most suitable, as the import of products and materials aligns with this method and not with the production-based normalisation method.

As the normalisation method is not considered a critical function of the MATS regulation, the specific functioning and practical implementation of the method will not be considered in this research. The practical implementation of the normalisation method and its impact on the permit price calculation must be established in further research.

Weighting Methodologies

This section explores the existing methods used to weight the 16 Life Cycle Impact Analysis (LCIA) impact categories into a single value. Each method's functioning will be elaborated. The LCA weighting methods compiled by Askham will be considered in this research (Askham et al., 2025).

The four types of weighting methods identified by Askham are:

- Monetary methods can involve stakeholders and lead to a single measure (in monetary terms)
- MCDA involves stakeholders and keeps the units in their original scale

- Data-driven methods need no stakeholder involvement and are based on the statistical properties of the dataset
- Distance-to-target methods need no stakeholder involvement, and weights are defined according to the distance from a scientifically determined target.

Applying a weighting method to the MATS permit price requires a single number that adequately addresses the environmental impact of the material in a single value, based on an empirical method that is undisputed. The first two methods rely on a panel that determines the subjective importance of a limited set of indicators. These methods are not suitable for large scale policies, as the individual values of the panel are too objective and not repeatable for large scale regulations. Data-driven methods are also not applicable as they mostly compare two alternative products. The distance-to-target method is most applicable because the distance-to-target method:

- Reflects equal importance for all environmental impact categories, making it less subjective than other weighting methods,
- and subjective values can be accounted for by other factors that determine the permit price
- is relatively transparent, easy to communicate, low stakeholder burden; aligning directly with planetary boundaries

Planetary Boundaries Distance to Target Weighting

Planetary boundaries (PBs) have increasingly been used as a basis for normalisation and weighting in Life Cycle Assessment. Conceptually, PBs link product-scale impacts to a global safe operating space, making it possible to contextualise LCA results against planetary boundaries rather than only relative to other products (Paulillo and Sanyé-Mengual, 2024; Sala et al., 2020). As the MATS policy applies to all materials, an alternative reference point to weight the impact against increases the objective value of the weighting method. Recent work distinguishes three main integration modes: LCA-based absolute environmental sustainability assessment (AESA), PB-based normalisation, and PB-based weighting (Paulillo and Sanyé-Mengual, 2024). PB-based normalisation uses global or regional carrying-capacity values as reference flows so that indicator results are expressed as a fraction of the available safe operating space, while PB-based weighting interprets the "distance-to-boundary" as an importance factor across impact categories (Paulillo and Sanyé-Mengual, 2024; De Laurentiis et al., 2023).

Methodological developments have focused on harmonising PB control variables with established LCIA indicators, defining and allocating the safe operating space, and addressing spatial and temporal dimensions (Paulillo and Sanyé-Mengual, 2024; Bjørn et al., 2020). For the EU Environmental Footprint framework, LCIA-based PBs have been quantified for multiple impact categories, enabling a planetary-boundaries-based normalisation set that can be directly combined with standard EF indicators (De Laurentiis et al., 2023; Sala et al., 2020). Comparative analyses applying several normalisation sets to large product portfolios show that the choice of PB-based versus production- or consumption-based normalisation strongly affects the relative importance of impact categories, often more than the choice of weighting set, highlighting the interpretative power and sensitivity of normalisation choices (De Laurentiis et al., 2023). Systematic reviews of LCIA normalisation methods now identify planetary-boundaries-oriented approaches, alongside global and regional normalisation, as one of the three main families of practice, reflecting a broader shift toward aligning LCA with global and regional sustainability thresholds.

At the operational level, PBs have been translated into corporate and sectoral tools where impacts are normalised and weighted against PB-derived references to generate single scores for decision support. An example is L'Oréal's SPOT eco-design tool, in which multiple environmental indicators are first normalised and then weighted based on PB concepts and aggregated into a single product footprint (Vargas-Gonzalez et al., 2019; L'Haridon et al., 2023). Sectoral and regional case studies apply PB-LCA to electricity systems, hydrogen production, wastewater management, bioeconomy and biorefineries, typically by comparing life-cycle impacts with allocated shares of global or regional safe operating space to assess transgression and to identify priority impact categories and processes (Sala et al., 2020) (Sala et al., 2020; Lima et al., 2023; Bjørn et al., 2020; Zeug et al., 2021; Hernandez-Arango et al., 2025; Weidner et al., 2022; Stranddorf et al., 2023). At the same time, conceptual critiques emphasise that such LCA-based AESA applications remain inherently relative, due to strong assumptions about time and allocation that are needed to link static product system inventories to dynamic carrying capacities, suggesting that PB-based normalisation and weighting should be framed as providing absolute "context" rather than truly absolute sustainability judgments (Paulillo and Sanyé-Mengual, 2024; Guinée, Koning, and Heijungs, 2022).

Applying the PB DtT method to MATS

A trivial example will now be presented to visualise the functioning of the planetary boundaries distance-to-target method to the MATS policy. For each material, the environmental impact is calculated. After which the results are normalised and weighted using the reduction factors by (Vargas-Gonzalez et al., 2019).

The weighting factors are calculated by determining the overshoot of each planetary boundary using a distance-to-target approach, which compares current global ecological pressures directly against the planet's carrying capacity (Vargas-Gonzalez et al., 2019). To establish these values, Life Cycle Impact Assessment (LCIA) results are first normalised using standard reference frameworks. The weighting factor, labelled reduction factors by Vargas-Gonzalez, are calculated according to Equation 4.1 by dividing the current quantified global impact by the scientifically defined carrying capacity. These ratios serve as the final weighting factors, ensuring that categories where human consumption have most severely transgressed the planetary boundaries receive proportionally higher weights.

$$Reduction\ Factor = \frac{Current\ Global\ Impact}{Carrying\ Capacity} \tag{4.1}$$

1 kg of material has 15 environmental impact category values representing all categories. Each value is compared to the yearly global value of that impact category to achieve the normalised value of that impact category. Compared to the global planetary boundary, the value of that material in that impact is for example 1.5E-13. The normalised value of that impact for 1 kg of the given material is multiplied with the weighting factor linked to that impact category, see Table 4.1. Using Equation 4.2, each material then has a single value that represents the impact of the production of that material.

TABLE 4.1: Weighting Factors by (Vargas-Gonzalez et al., 2019)

n	Impact Assessment Indicator	Weighting Factors w_n
1	Climate change	9.36
2	Ozone depletion	0.28
3	Human toxicity (cancer effects)	0.26
4	Human toxicity (non-cancer effects)	0.90
5	Particulate matter	5.97
6	Ionizing radiation	0.01
7	Photochemical ozone formation	0.54
8	Acidification	0.53
9	Terrestrial eutrophication	0.30
10	Freshwater eutrophication	3.22
11	Marine eutrophication	0.55
12	Land use	9.33
13	Freshwater ecotoxicity	0.85
14	Water resource depletion	0.51
15	Mineral & fossil resource depletion	4.08

The weighting factors are applied to the price calculation formula as follows:

$$p_{nw} = \sum_{n=1}^{15} w_n \cdot i_n \tag{4.2}$$

Where:

- p_{nw} is the price calculated by normalisation and weighting
- w_n is the weighting factor for each category
- i_n is the normalised impact of 1 kg of material
- n are the 15 impact assessment indicators

We end up with a list of all materials (or a selection) with values that represent the weighted impacts that 1 kg of each material contributes. values will probably vary between a really small number and a slightly larger number (E-13 - E-10). Converting the values to a logarithmic scale can be done to put every value in the same few orders of magnitude.

If we take copper as an example, a database such as ecoinvent identifies multiple methods to produce copper. Imported materials must then be categorised under one of the approximately 26,000 ecoinvent datasets (Ecoinvent, 2026). A load of raw copper and a shipment of cars enter a European port. The raw copper pays a MATS import tax that represents the environmental impact of extraction of that raw copper, the processing into pure copper, and the shipment to the European port. The imported cars require to state the copper content in each car such that the environmental impact of extraction of that copper, processing of that copper, the production of the car, and the shipment of the car can be determined. The life cycle of each kg of copper up until the EU border will be translated into the permit price for that specific kg of copper.

4.2.2 Problems with directly implementing N&W values

Applying that calculated permit price directly will result in some problems. These problems will be explained in this section. The first category of problems are linked to the validity of LCIA normalisation and weighting methods. First, LCIA weighting and normalisation are fundamentally value and method dependent. Different LCIA methods, weighting sets and normalisation references can change relative scores or even invert which option scores "best". If permit prices are tied directly to a specific weighting set, the whole policy depends on a scrutinisable methodological choice. Second, LCIA methods are more dependent on some impact categories than others. Studies show that current weighting approaches (linear weighted sums after normalisation) are often insensitive to the chosen weights and dominated by a few impact categories whose normalized values are largest. This means the implied "exchange rates" between impacts in a single LCIA score do not transparently or reliably represent stakeholder preferences. Using those same scores as permit prices would silently import these distortions into the policy, privileging some impact categories (e.g. climate, fossil depletion) and marginalising others (e.g. toxicity, water use) in a way that is hard to explain or defend. These points make the justification for directly implementing these values hard. Although a distinction must be made between higher and lower impact materials, an intermediate step might be necessary for a cap price.

A second category of issues come from implementing tax systems. Although tax systems are outside the scope of this thesis, it is important to note that this is an issue that can be solved in many ways, most of them known and solved in the past. Future research must be done to identify the best taxation method applicable to the normalised and weighted values of the MATS policy. As the permits are a form of taxation, a similar problem within the tax system must be evaluated to come to a solution. Solving this problem can be done in a variety of ways, such as price brackets for different levels of environmental impact.

4.2.3 Further Research on Permit Pricing

Because of the PB DtT method chosen, the system will result in prices representing environmental footprint that embeds all environmental footprints of that material up to that point of the supply chain. The LCA of the method incorporates all the life cycles from extraction until the border. The weighted price is a relatively subjective figure, therefore, a the sensitivity analysis should be done to calculate the permit price shifts when material contents shift. A sensitivity analysis should be done to show how the total environmental impact and therefore the permit price of a product changes when the percentage of material contents shift. The precision of the method to represent the environmental impacts of a material requires further research. Further research on the methods to determine the material contents of products and methods to verify this data is required. The MATS regulation applies a tax on imported goods, and the import duty system has overlap with the MATS regulation. Integrating the import duty system is a possibility to resolve this overlap. Further research is required to weigh the different factors influencing the permit price, as environmental impact might be only one aspect of the calculation. Other factors such as the monetary value of products or materials, or a factor that scales the determined prices, or other unknown factors can have influence on the permit price calculation. The factors must answer the question how societal impacts and interests are integrated into the permit prices.

4.3 Proposed regulatory framework, the Material Allowance Trading Scheme

The results from this chapter are now summarised in a proposed regulatory framework, the initial concept of the Material Allowance Trading Scheme (MATS), conceptually modelled after the European Union Emissions Trading System (EU ETS). Its purpose is to reduce the total environmental impact of the European economy by capping and gradually reducing the amount of materials entering the European economy each year. The cap will be set on the weight of material flow into the economy. The EU ETS will be the blueprint for the MATS policy, as the ETS is a contemporary environmental regulation that successfully reduced greenhouse gases within the EU. While the EU ETS regulates emissions of greenhouse gases using a single comparable metric (CO_2-equivalents), a material trading system faces greater complexity: materials differ widely in their environmental impacts. To address this, the proposed policy combines a mass-based cap on material use with an environmental weighting mechanism that adjusts permit prices according to each material's environmental impact. Figure 4.3 visualises the functioning of the MATS policy.

Reflection on the chosen regulated metric
The mass-based approach was chosen for the MATS regulation in this chapter because it is more intuitive and transparent than the other options. However, an environmental impact-based regulated metric has its own advantages and disadvantages. For one, an environmental impact-based approach would not require setting a separate cap for every individual material, as all imported goods would simply be converted into their corresponding environmental impact. There are already examples of this in existing policies; under the Renewable Energy Directive program, producers must calculate the CO2 impact of bio-methane themselves, and these calculations are then accepted under EU regulations. In a similar way, the MATS regulation could require importers to calculate their environmental footprint across all 15 impact categories to determine how many permits they need to buy. On the other hand, this method would significantly increase the bureaucratic burden on companies. For this reason, among others, the mass-based approach was selected as the primary option. The mass-based approach also works better than the environmental impact-based approach because the weight of imported goods can be measured directly, avoiding the less transparent calculations needed to turn imports into environmental impacts. Instead, the environmental impact can be calculated in the back-end of the regulation to monitor overall environmental improvements.

As the MATS policy will be modelled after the ETS, limitations of the ETS that might be translated into the MATS must be discussed. A literature study on the limitations of the ETS will be done to identify its limitations. Some limitations identified will apply to the general design of the MATS policy, which will be discussed in this chapter.

As will be explored in this chapter, various aspects of implementing LCIA normalisation and weighting derived permit prices result in technocratic, democratic, and value concerns. This chapter aims to address these concerns in order to shape a holistic answer to the question of what an effective material cap and trade system would look like.

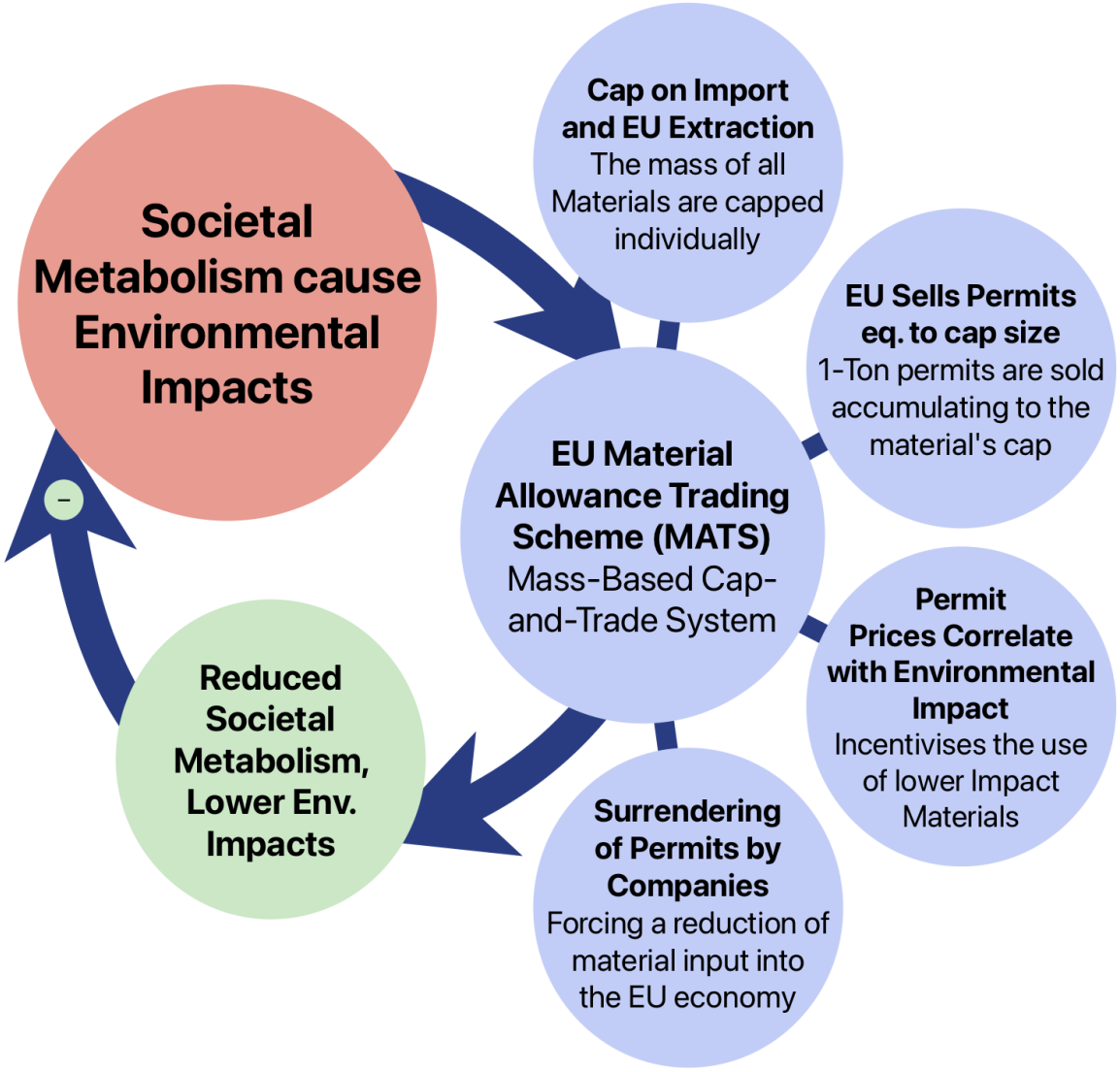


FIGURE 4.3: Basic functioning of the MATS policy proposal

4.4 Explanation MATS

The Material Allowance Trading Scheme (MATS) is a proposed plan to limit the total amount of natural resources used in the European Union. It is based on the idea that the economy should not use more materials than the Earth can safely provide.

4.4.1 Why is MATS needed?

Currently, the EU uses about 14 tonnes of material per person every year. However, scientists believe a sustainable amount is only 5 to 8 tonnes. While the EU has rules to make production more efficient, those rules have not stopped the total amount of resources from increasing. MATS aims to fix this by setting a strict limit on the total weight of materials entering the economy.

4.4.2 How the System Works

The goal of MATS is to put a price on "using the Earth" so that businesses naturally choose more sustainable options. The functions described below that are not discussed in this report are assumed analogue to the EU ETS functioning which serves as blueprint for the MATS regulation (Bayer and Aklin, 2020).

- The Cap (The Total Limit): The EU decides on a "budget" for how many millions of tonnes of materials the entire economy can use in a year. This is not one big cap; it is broken down into individual materials like iron ore, oil, and wheat to make sure companies cannot switch from one harmful material to another.
- Permit Allocation and Surrender: For every tonne of material a company extracts or brings into the EU, they must "surrender" one permit to the EU customs. These permits are sold at auctions, and the permit prices are determined based on the material's environmental impact.
- Reducing Limits Over Time: The cap is lowered every year. By reducing the number of permits available annually, the EU forces the economy to slowly adopt to using fewer resources until it hits a sustainable target (around 5–8 tonnes per person) by 2050.
- Impact-Weighted Pricing: Instead of every tonne costing the same, the price changes based on how much "environmental damage" that specific material causes. Using a method called Life Cycle Impact Assessment (LCIA), the system looks at 15–16 factors such as how much water is used or how much toxic waste is created, to calculate the final price of the permit.

4.4.3 Who Is Affected

The regulation targets the "entry points" of the economy to make sure nothing enters the EU without being accounted for.

- Extractors (Mining and Agriculture): These are the companies that take resources directly from the land within the EU. Under MATS, a mining company cannot just dig up iron ore and sell it; they first have to buy the permits for that weight. This makes "virgin" (newly mined) materials more expensive than recycled materials, which do not require these permits.
- Importers of Raw Materials: Since the EU buys many resources from other countries, importers act as the "gatekeepers." When a ship full of copper or coal arrives at an EU port, the importing company is responsible for handing over the correct number of permits. This ensures that materials from outside the EU are treated the same as those produced inside.
- Finished Goods Manufacturers: If a company imports a car or a computer, they must prove exactly what is inside it. They use a "Material Passport", a digital document that lists the weight of every component (the steel frame, the copper wiring, the plastic dashboard). The importer then pays for permits based on the total weight of all those different materials combined.

4.5 Material Cap-and-Trade Regulation Design Summary

In this chapter we transitioned from the shortcomings identified in the literature review to the conceptual design of the Material Allowance Trading Scheme (MATS). The literature established that current policies relying on the green growth/decoupling paradigm and that they are insufficient to keep societies within planetary boundaries. This chapter systematically addressed this gap. It provides a conceptual design of a regulatory framework of a material cap-and-trade system aimed at reducing EU's material and environmental footprint below planetary boundaries.

This chapter concludes that a mass-based cap regulation is required for the EU to become a society within planetary boundaries. Key findings include the necessity of separate material caps for all imported and extracted materials, and the implementation of a permit system where prices reflect aggregated environmental damage across the 16 environmental impact categories. Furthermore, the analysis demonstrates that the scheme must eventually account for the material content of imported finished products to prevent leakage or material rebound effects.

Chapter 5

Discussion

In chapter 1, the current state of the environment and environmental policy was identified and a problem statement was selected for this research. The research aim was to develop a conceptual material cap-and-trade EU regulation that will steer the EU environmental footprint below planetary boundaries. Using the methods of a traditional narrative literature review structured around a problem-solution perspective, and a modelling exercise to transform existing policy data into a new conceptual regulatory design. The outline of this chapter will be as follows: section 5.1 aims to discuss the results found in chapter 3 and chapter 4, section 5.2 will cover the implications of the results, section 5.3 covers the limitations of the research, section 5.4 covers the contribution of this research to the academic debate, and section 5.5 will cover the answer to the research questions.

5.1 Recap of Results

This section covers the major findings of this research and the meaning of those results from chapter 3 and chapter 4.

5.1.1 Literature Review Results

The literature review identifies a fundamental misalignment between the EU's policies and the planetary boundaries. Findings in section 3.1 establish that the EU's societal metabolism causes the overshoot of the EU's planetary boundaries. The prevailing environmental policy paradigm, characterized as the "green growth" model in subsection 3.2.1, relies on efficiency gains and technological substitution to achieve decoupling. However, the review of historical data reveals that absolute decoupling between GDP and total resource use remains absent at the scale and speed necessary for global sustainability. This suggests that efficiency gains are consistently offset by economic expansion, leading to a net increase in environmental pressures.

Furthermore, subsection 3.2.2 highlights that current regulatory frameworks aimed to reduce the EU's environmental footprint such as circular economy are largely restricted to recycling and waste management, failing to address the structural drivers of material throughput. The governance problem space, examined in subsection 3.2.3, is defined by a gap in institutional policy tools where no binding regulations exist to constrain the total volume of materials entering the economy. This policy failure necessitates a shift toward governance where planetary boundaries are set as guiding requirements for new regulations.

An analysis of the EU governance style in subsection 3.3.3 indicates that market-based competition instruments, such as the Emissions Trading System (ETS), represent the most effective

and politically viable path for large-scale environmental intervention. The results in **??** synthesize these findings, concluding that a macro-scale resource cap is the required policy ingredient to steer the EU's material footprint back into a safe operating space. By transitioning from productivity-based indicators to science-based, binding footprint targets, the proposed Material Allowance Trading Scheme (MATS) addresses the identified gap between planetary boundary science and institutional policy.

5.1.2 MATS design Results

The main findings from chapter 4 can be summarised as follows. The MATS conceptually captures a solution to the need for environmental policy that effectively steers the EU economy to within planetary boundaries. The MATS design consists of design options for the functioning of cap and the permit. A mass-based cap, with reduction target to PB by 2050, with permits for the import or extraction of 1 ton of material into the EU, and permit prices based on the environmental impacts. In the following sections, the implications of the MATS design will be discussed.

The mass-based approach was selected for the MATS regulation in chapter 4. The selection of the mass-based regulated metric (the focus of the governance/the unit that is governed), has been among other reasons chosen as most intuitive and transparent of the options. On the other hand, the environmental impact based regulated metric has some advantages and disadvantages over the mass-based approach. As the environmental impact-based approach would not require the separate cap of individual materials, but converting the imported goods to environmental impact. In existing policies, for example the Renewable Energy Directive programme, the CO2 impact of for example bio-methane has to be calculated by the producer themselves, and those calculations are adopted by the EU regulation. Similarly, the MATS regulation may require importers to calculate their environmental footprint for all 15 impact categories for which they will require the purchasing of permits. However, this approach increase the bureaucratic burden on companies the most. Therefore and among other reasons, the mass-based approach was selected as primary option. The mass-based approach also has an advantage over the environmental impact based approach as the mass of imported goods can be measured directly, without the less transparent calculation of converting imported goods into environmental impacts. The environmental impact is calculated in the back-end of the regulation to check the environmental impact improvements.

5.1.3 Main findings

The results show that the debunked decoupling paradigm calls for an alternative future for future EU environmental policy that can effectively limit the EU's environmental impacts. Consequently, the need expressed in literature for the conceptual development of an impact-reduction-focused regulation is considered critical in furthering the scientific discussion on adequate EU environmental policy. This thesis contributed to this contribution by presenting a conceptual design of the Material Allowance Trading Scheme (MATS).

5.2 Implications of the Resource Cap

The scientific debate on resource caps has, until now, been entirely devoted to a discussion on the potential societal and economic impacts of this regulation (Kelly, 2024; Meysner, Gore, and IEEP, 2022; Ekins et al., 2014). The societal and economic implications of the MATS design are therefore well-documented. Although this research does not address these implications, it can serve as a tool to concretise the discussion towards urgent questions on resource caps of

societal, public management, policy design, and economic nature. This section covers the main questions on resource caps aimed at steering further research.

International Trade
Resource caps have been identified as a threat to international relations and free trade (Klossek, Kullik, and Boogaart, 2016; Ekins et al., 2014). A resource cap is a form of trade barrier, and, although outside the scope of this report, the concrete implications of trade barriers can have negative implications on the economic wellbeing of the regions (Harrigan, 2003). As a resource cap has significant implications on international trade, the approach to international relations within the context of a resource cap requires further research.

Development Potential
Reductions in resource use has been identified as a possible barrier for the individual, industrial and state development potential (Alcott, 2010; Kallis and Martinez-Alier, 2010; Kelly, 2024; Ekins et al., 2014). This debate surfaces with the post-growth literature on how societies can flourish within planetary boundaries (O'Neill et al., 2018; Schmelzer, Vetter, and Vansintjan, 2022; Büchs and Koch, 2017). Can societies maintain the individual, industrial and state development potential while staying within planetary boundaries? And if the development potential is in conflict with planetary boundaries, what decision should be made? The ongoing debate on the question whether developed societies can exist within planetary boundaries is fundamental for the legitimacy of the resource cap, although research shows that societies can thrive within planetary boundaries (O'Neill et al., 2018).

Democratic Representation
Aside from the theoretical question whether societies can exist within planetary boundaries, a concrete question emerges how policy tools, such as resource caps, must be implemented (Kallis and Martinez-Alier, 2010). If the decision is made that a resource cap shall be implemented, public management processes, political science and governance are required to maintain democratic decision-making. The potential political power of resource caps have raised concerns of (eco-)authoritarian mis-use (Kelly, 2024). A distinction is made between regions with high impact environmental policies with low levels of democracy such as China, and regions with lower impact environmental policies with stronger democratic governance such as the EU. However, this false dilemma does not hold since policies with high impact potential such as the ETS exist within the strong democratic regions. The environmental results are less extensive since democratic stakeholder management results in slower transformation, but the regulations have the same potential power as those in regions with lower democratic representation. The resource cap is presented as potentially dangerous regulation, but the similar EU ETS has similar functions and is governed according in EU governance style.

For example, the power to set emission caps, control emission permit prices, and penalise industries that do not comply regulation is done by independent regulatory authorities with the member states, such as the Dutch Emission Authority in the Netherlands (Emissieautoriteit, 2025). This avoids the potential prioritisation of political interests over industry interests. Also, the complicated nature of the regulation for a large number of individual cases makes the regulation unsuitable for operation by a ministry or DG. These concerns align with the concerns over democratic representation of the resource cap:

1. The political interests on the functioning of MATS are framed as susceptible for eco-authoritarian abuse, as power over the life-lines of industries (their material input), can have political consequences (Kelly, 2024; Kallis and Martinez-Alier, 2010).

2. such a policy requires the complex governance of trade where a large amount of red-tape

is required for the policy to work. For a large number of individual cases, paperwork is required to determine the material content of imports, the validation of that data, the system required for purchasing, surrendering, and trading of material permits, etc (Kallis and Martinez-Alier, 2010).

3. If governments decide on the yearly reductions of material input to the EU and industries are not consulted, the interests of industries that are affected by the regulation can be neglected with great economic impacts on those industries. Therefore, the interests of the private sectors should have influence on the application of the policy (Kallis and Martinez-Alier, 2010).

As was learned from the implementation of the EU ETS, the answer in public management to these concerns is the independent regulatory authority/agency. Originating from national governments such as the Dutch Zelfstandige Bestuursorganen (Independent Administrative Bodies), criteria for the creation of an independent regulatory authority are in the case of ZBO's (Koninkrijksrelaties, 2026):

Article 3.1: An independent administrative body may only be established if:

a) there is a need for independent judgment on the basis of specific expertise;

b) there is a matter of strictly rule-bound implementation in a large number of individual cases;

c) the participation of civil society organizations is deemed particularly appropriate in connection with the nature of the administrative task involved.

The identified categories of potential societal impacts 1, 2, and 3 correspond to the components of article 3.1 a, b and c of the kaderwet zelfstandige bestuursorganen (Framework act Independent Administrative Bodies) respectively.

An independent regulatory authority of the EU is likely the best option for adopting and enforcing the MATS regulation. The authority, focused on the material imports can either be adopted within the European Customs Authority, or a separate "European Material Import Authority" can be established. The independent regulatory authority has the power to formulate and enforce regulations based on specific scientific expertise on the subject. The MATS regulation will be separated from political interests, handled by a specialised authority, and co-shaped with industries affected by the regulation. Further elaboration on the implementation of the regulation falls outside the scope of this thesis, and further research is required for the implementation of resource caps within democratic boundaries.

5.2.1 MATS within the Policy Landscape

On the one side, the MATS regulation can be implemented in the current policy landscape, for example within the EU Green Deal visualised in Figure 5.1. It could become part of the "Resource" pillar, distinct from the current waste management and efficiency regulations, but it still can fit within the resource pillar of the EU's sustainable regulation landscape.

The circular economy is another important aspect of future environmental policy relevant to the MATS regulation, as the circular economy aims to reduce the virgin material input of economies. Therefore, a more applicable policy landscape for the MATS regulation could be

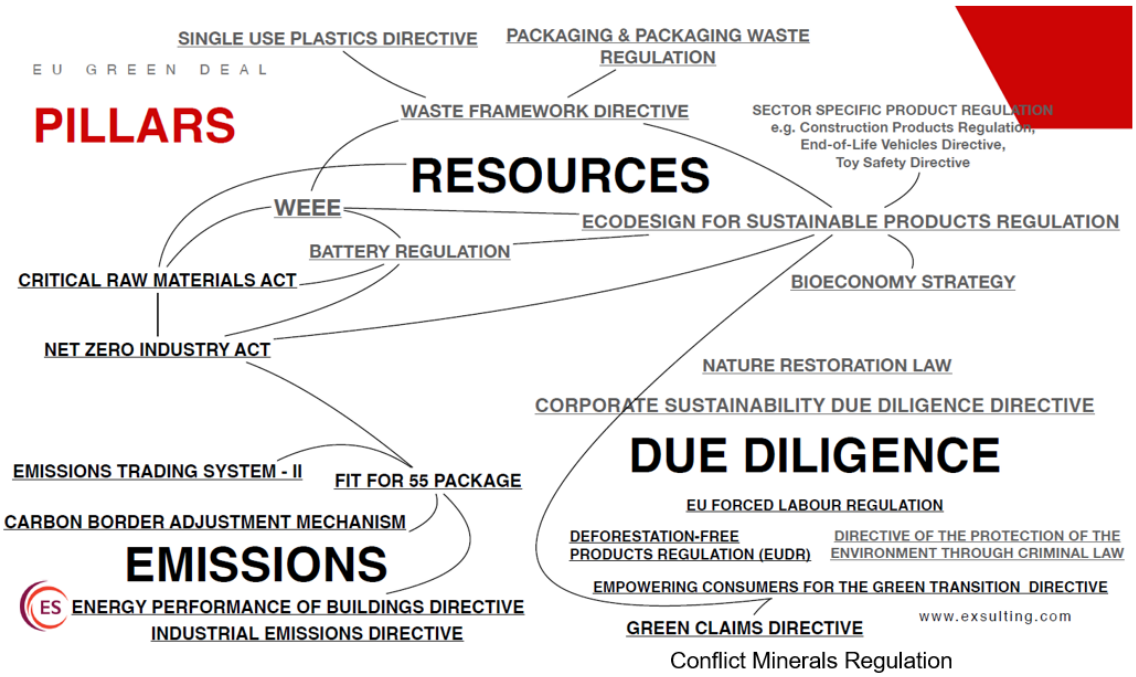


FIGURE 5.1: EU Green Deal Policy Landscape (exsulting.com)

within the Circular Economy landscape. Figure 5.2 shows the placement of the MATS regulation within the Circular Economy policy landscape by (Dalhammar, 2019). The MATS regulation fits within the consumption policy category of the Circular Economy, potentially serving as guardrails for the implementation and effectiveness of the Circular Economy.

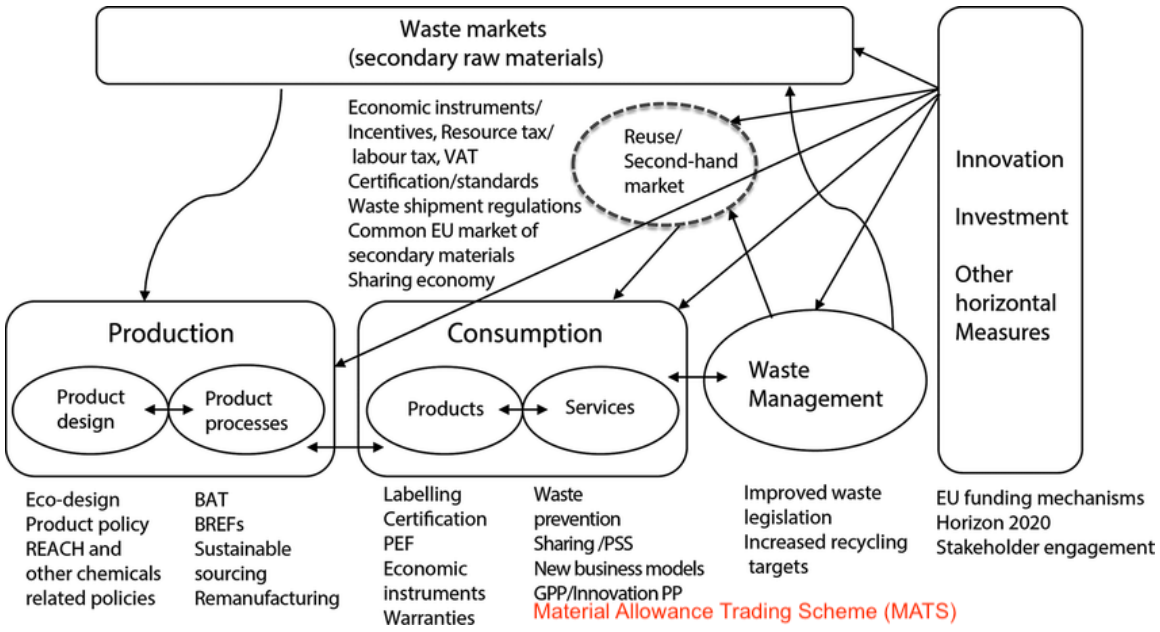


FIGURE 5.2: The MATS regulation placed within the Circular Economy Policy Landscape (Dalhammar, 2019)

On the other side, implementation of the MATS regulation in the current policy landscape can be seen as a new chapter of environmental policy, not an amendment to the current policy landscape. The ethos of the MATS regulation does not fully overlap with the current landscape, again, comparing with the "Resource" regulations within the EU Green Deal. The new chapter of EU regulation can be categorised as post-growth regulations and policies with other policies aimed to reduce the EU's environmental impact below planetary boundaries.

Within the literature on transforming policies to focus on human and planetary wellbeing, Kate Raworth can be seen as a figurehead setting out a general direction for future policies (Raworth, 2017). In Doughnut Economics, Raworth argues that correcting global ecological overshoot requires moving beyond market-based interventions and instead embedding ecological boundaries directly into macroeconomic policies. Her framework rejects the assumption that economic growth will naturally resolve environmental degradation. She advocates instead for a structural transition toward an economy that is sustainable. The MATS regulation fits within this emerging policy landscape that is mostly only discussed in literature and not yet applied.

It should be re-emphasised that the current policy paradigm of developing and implementing renewable energy sources and other sustainable technologies is insufficient to achieve full sustainability, but necessary to reduce climate change and relevant until net-zero emissions are achieved. The MATS regulation can be seen not as the replacement of the current policy paradigm, but an addition and only later on the required policy focus.

5.3 Limitations of the research

The outcomes of the research require reflection on the limitations of the research approach used and the limitations of its outcomes. Throughout chapter 3 and chapter 4, many limitations and calls for further research has been stated. In this section, these will be summarised and complemented.

5.3.1 Literature Review Limitations

Considering the limitations of the literature, the following elements can be identified. Within the literature, a line of reasoning was chosen where each step was the "logical" result of the previous step. As the literature review covers a relatively long line of reasoning, the end result is a product of a set of logical steps. Each step is subject to debate, and therefore, the end result is only one possible solution to the problem defined in subsection 1.2.1. Although each step is well-argued, many different lines of reasoning were possible, with many different outcomes.

Another limitation of the research is the literature not identified in the literature review. Although the widest range of academic insights was sought, some literature with competing arguments might have been overlooked. Further research on the validity of the line of reasoning might reveal flaws within this literature review. Reliance on secondary literature likely resulted in the under-representation of practice-based knowledge held by policymakers and stakeholders.

5.3.2 MATS Design Limitations

The main limitation of the MATS design was the overall depth of analysis of the design options. Due to the limited resources available during this research, the depth of the design options was limited. The main goal was to fill the gap between scientific knowledge of planetary boundaries and effective policy design, two large subjects which required extensive research. Therefore,

the design of the regulated metric only considered four options, monetary-based, product-based, environmental impact-based, and mass-based, and other options were not considered but might exist. The preliminary design of the options also did not consider all design aspects and implications, and the rejection of methods might be pre-emptive or invalid due to wrong assumptions or solutions not considered. For example, the rejection of a product-based cap was based on the assumption that bulk products cannot be counted as product units, but a solution to this issue might reinstate the product-based cap as option for the resource cap. These limitations apply to the entire chapter and all design choices considered in chapter 4. Besides the apparent limitations, the conceptual design phase did illustrate the possibilities and barriers when considering different design options. The resulting conceptual Material Allowance Trading Scheme does illustrate the basic functioning, and the framework can be used for further discussion on the topic in further research.

DPSIR Framework Applied to the MATS

The analysis of the environmental impact-based cap was limited to an abstract description. Further development of functioning of a environmental impact-based regulated metric can be done to explore the option further. Specifically, the analysis of the environmental-impact regulated metric can be linked to the DPSIR framework and an LCIA approach (European Environment Agency, 1999).

The DPSIR framework, visualised in Figure 5.3, is an analytical structure based on a systems analysis view that outlines the causal chain of connections between human society and the environmental system. Within this structure, social and economic developments serve as driving forces (D) that exert pressures (P) on the environment, thereby altering its physical, chemical, or biological state (S). These alterations subsequently lead to impacts (I) on ecosystems, human health, and materials, which eventually elicit a societal response (R) that feeds back directly onto the drivers, pressures, states, or impacts. The framework's primary purpose is to provide policy-makers with a structured means of managing, analysing, and interpreting diverse environmental indicators (European Environment Agency, 1999).

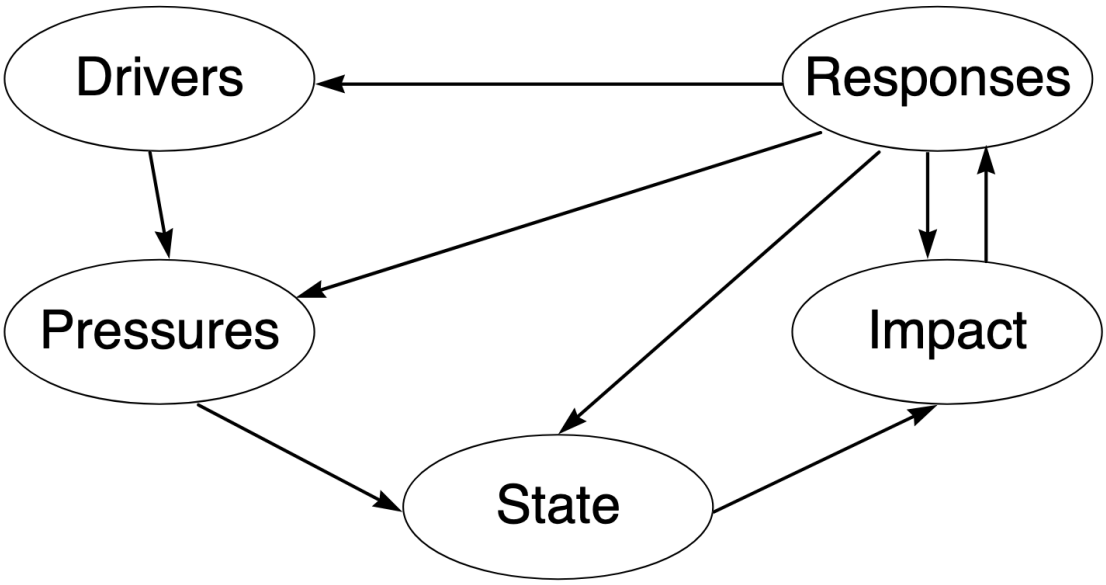


FIGURE 5.3: DPSIR framework (European Environment Agency, 1999)

By contrasting the MATS regulation against the DPSIR framework, the functioning of the regulation can be clarified further. The DPSIR framework could apply to MATS by identifying material imports and extractions as Drivers that create environmental Pressures (emissions and resource use), which are then modeled through LCIA to determine the resulting State of environmental indicators. This allows for a targeted policy Response, the MATS cap-and-trade system, which regulates physical mass inflows based on their weighted Impacts on planetary boundaries.

5.4 Contribution to Academic Debate

The main contribution to the academic debate in the literature review is a fundamental line of reasoning on the need for an EU resource cap. Literature on resource cap has until now been theoretical and has not been applied to a concrete context. By reasoning from the fundamental absence of adequate environmental policy to tackle the problem of exceeding planetary boundaries, and constructing the required policy framework from conceptual policy theory, the need for an EU resource cap is fundamentally grounded in a literature. There is a clear gap between the problem statement of the world's and the EU's exceeding planetary boundaries and the inadequacy of current policy proposals. This literature effectively fills that gap and proposes that applying a resource cap has a high potential to effectively reduce the environmental footprint below planetary boundaries.

The second contribution to literature is the conceptual design of the MATS regulation as framework for further research and policy design. The initial design consisting of preliminary design considerations is the first step in demonstrating the potential functioning of a resource cap within EU context. The purpose of the conceptual design is to establish a rough starting point that requires design iterations leading into a mature policy proposal. The conceptual design identifies many flaws and unanswered questions that need solutions, and therefore can be seen as a research agenda for further research.

5.5 Answering the Research Question

The following section synthesises the findings of this thesis to provide comprehensive answers to the research questions established in subsection 1.2.3 and subsection 1.2.4.

In response to the first sub-research question concerning which regulatory framework can potentially steer the European Union below planetary boundaries, the research identifies a resource cap-and-trade system as the most viable mechanism. This identification stems from the recognised inadequacy of current green growth/decoupling policies, which rely on efficiency gains and relative decoupling that have failed to reduce the EU's overall environmental footprint due to rising material input of the EU. By shifting the focus to absolute reductions in material throughput, a resource cap-and-trade system directly addresses the scale of the EU's societal metabolism.

Regarding the second sub-research question, the critical design elements for applying such a system to resource use are determined to be the regulated metric and the permit price calculation. While modelled after the architecture of the EU ETS, a material-based system requires an alternative for single-metric indicators like CO_2-equivalents due to the diverse environmental impacts of different material flows. The mass-based cap was found to be the most objective and efficient regulated metric capable of regulating the material input of the EU. Secondly, the Planetary Boundary Distance to Target method was found the best fit for the requirements of

objectiveness, repeatability, and transparency. These two elements are fundamental to ensuring the regulation is both scientifically robust and practically enforceable within the European context.

Addressing the third sub-research question, the conceptual design of these critical elements translates the abstract concept of a resource cap into a conceptual EU regulation through the development of the Material Allowance Trading Scheme (MATS). By establishing a mass-based cap on material throughput, and integrating an impact-weighted pricing mechanism, the MATS ensures a direct link to planetary boundary targets. This approach allows the regulation to govern the physical weight of materials entering the economy while adjusting permit prices to reflect specific environmental impacts identified through Life Cycle Impact Assessment.

Finally, the main research question is answered by concluding that the conceptual design of the MATS regulated metric and permit price provides a framework capable of advancing the scientific discussion on future EU regulations. By offering a structured and novel design that bridges the gap between scientific knowledge of planetary boundaries and concrete policy formulation, this thesis demonstrates that the MATS proposal captures the essential outlines of an effective regulatory system. This conceptual development serves as a foundation for further research into reducing the European environmental footprint to levels compatible with the Earth's safe operating space.

5.5.1 Summary of Discussion & Final Remarks

What we have seen in the report and in this discussion can be summarised as follows. The MATS regulation potentially fills a gap between the scientific knowledge of exceeding planetary boundaries and effective regulatory frameworks capable of reducing the exceeding planetary boundaries. What we have also seen are objections to this concept primarily in this chapter. For all objections stated in this chapter and in literature, this report has 3 answers. First of all, a MATS regulation is a viable policy framework which can be implemented in the EU policy landscape. Secondly, on the other hand, the MATS regulation requires a shift in policy paradigm which requires further research, consensus, and a paradigm shift in the EU policy landscape and public support. Thirdly, this report is a small step in the scientific debate which aimed to fill the gap identified before such that further research can discuss the concept of a resource cap using a semi-concrete regulatory framework. The analysis has many limitations which must be addressed in further research, resulting from the limited resources available during this research. Nonetheless, this report reflects a crucial general direction for further research on future environmental policy approaches.

Chapter 6

Conclusion

The environmental challenges facing the European Union and the wider global community are rooted in a fundamental misalignment between industrial activities and the biophysical limits of the Earth system. As established in section 1.1, the current trajectory of global material use persists in an upward trend despite an array of international and regional policy frameworks intended to foster sustainability. Within the European context, the transition toward a Circular Economy has largely failed to achieve the necessary absolute decoupling between economic expansion and environmental degradation. Instead, as discussed in subsection 1.2.1, efficiency gains are consistently outpaced by the volume of consumption and production, leading to a Domestic Material Input that continues to rise. This thesis identifies a critical research gap: while the scientific community recognises the need for resource use caps to respect planetary boundaries, there is a distinct absence of concrete, conceptual policy designs to facilitate this transition. Consequently, the research aim articulated in subsection 1.2.2 was to translate abstract biophysical limits into a structured regulatory framework, specifically the Material Allowance Trading Scheme (MATS).

The pursuit of this objective required a methodology capable of bridging environmental science with policy formulation. section 2.1 describes the use of a literature review structured through a problem-solution lens. This approach allowed for the systematic identification of the ecological and governance drivers behind the current crisis while mapping the theoretical landscape of potential solutions. Central to the development of the MATS was the modelling exercise detailed in section 2.2. By treating the existing architecture of the EU Emission Trading System as a blueprint, this research selectively imitated the agenda-setting and policy formulation stages of the policy cycle. The EU ETS provides a proven mechanism for competition-based governance that aligns with the established policy style of the European Union, as further explored in subsection 3.3.3. The resulting model serves as a representational instrument to reason about a future where material throughput is constrained by scientific targets rather than market demand alone.

The literature review findings presented in chapter 3 underscore the severity of the ecological problem space. section 3.1 highlights that human societies now act as a dominant force shaping Earth-system dynamics, with the EU's societal metabolism operating well beyond its fair share of planetary boundaries. The analysis in section 3.2 reveals that the prevailing "green growth" paradigm is insufficient because it treats environmental impacts as marginal externalities rather than structural outcomes of economic organization. This leads to the governance problem space where existing institutional policies are institutionally weak and fragmented. Findings in section 3.3 suggest that a paradigm shift toward Earth-system governance is required, where biophysical constraints become the primary and binding foundations for all economic activity. By synthesizing these elements in section 3.4, the research concludes that

a macro-scale resource cap, implemented through a cap-and-trade mechanism, represents the most viable path for steering the EU's footprint back into a safe operating space.

The core contribution of this thesis is the conceptual design of the MATS framework detailed in chapter 4. The selection of the regulated metric, discussed in subsection 4.1.1, was a critical design choice. After evaluating monetary, product, and impact-based indicators, a mass-based cap was identified as the most objective and enforceable metric for regulating total material throughput. In subsection 4.1.2, this metric is linked to science-based reduction goals, converging toward a sustainable target of 5 to 8 tonnes per capita by the year 2050. This target ensures that the EU's societal metabolism is physically constrained within boundaries that prevent irreversible ecosystem damage. To address the varying environmental intensities of different materials, section 4.2 introduces an impact-weighted permit pricing mechanism. By utilizing Life Cycle Assessment (LCA) data and the Distance-to-Target method, the scheme ensures that materials with higher ecological footprints such as those contributing to biodiversity loss or toxicity, carry a higher permit cost. This steers the market toward low-impact alternatives without the administrative complexity of managing thousands of individual product categories.

The regulatory structure of MATS, outlined in section 4.4, targets the primary entry points of materials into the European economy. By regulating extractors and importers, the system captures the total volume of materials at the source, thereby minimizing the risk of regulatory leakage and ensuring comprehensive coverage. subsection 4.4.2 explains how the tradeable permit system allows for economic flexibility, enabling those sectors that can reduce their material use most efficiently to do so first. Furthermore, the inclusion of Material Passports for finished goods, as proposed in subsection 4.4.3, provides the necessary transparency to account for the material content of complex imports. This ensures that the biophysical constraint is maintained across the entire value chain, preventing the outsourcing of material footprints to regions outside the EU's regulatory reach.

In the discussion of the results, section 5.2, among other implications of the MATS regulation, highlights the necessity of an independent regulatory authority to oversee the scheme. Drawing on existing administrative frameworks, the research suggests that a "European Material Import Authority" or a specialised branch of the European Customs Authority would be best suited to maintain the scientific integrity of the cap. Such an authority must be empowered to formulate and enforce regulations based on biophysical data, insulated from the short-term political pressures that often dilute environmental legislation. This institutional arrangement is vital for ensuring that the MATS remains a binding constraint.

The limitations of this research, acknowledged in section 5.3, emphasise the preliminary nature of the MATS design. The reliance on a specific line of reasoning from secondary literature means that other potential policy configurations may exist that were not explored here. Additionally, the rejection of certain metrics, such as product-based caps, was based on current technological and administrative assumptions that may shift in the future. Nevertheless, as argued in section 5.5, this thesis provides a fundamental contribution to the academic debate by offering the first concrete conceptualization of a resource cap within the EU context. It fills the gap between theoretical limits and practical policy, providing a research agenda for future design iterations.

Ultimately, this research demonstrates that aligning the European economy with planetary boundaries is not a theoretical necessity but a designable policy objective. The Material Allowance Trading Scheme provides a tangible framework for moving beyond the debunked relative decoupling and toward a future of absolute reductions in material throughput. By integrating biophysical constraints into the core of European competition governance, the MATS

offers a pathway for a truly sustainable societal metabolism that respects the ecological foundations of human wellbeing. The findings suggest that while the transition is complex, the mechanisms of cap-and-trade, when adapted for resource use, provide a robust and scientifically grounded tool for governance in the Anthropocene.

6.1 Further Research

The conceptual development of the Material Allowance Trading Scheme (MATS) establishes a foundation for absolute resource reduction, but it highlights several critical areas requiring subsequent scientific and policy investigation.

Future research must evaluate alternative design options for the regulation, as this thesis presents an initial baseline configuration intended for advancing the scientific debate. Each distinct design variation requires rigorous analysis regarding its suitability, advantages, and drawbacks. Further study is required to establish robust, criteria-aligned methodologies for determining individual material cap sises and their corresponding reduction trajectories. These methods must balance ecological targets with industry needs, taking into account current consumption, future projections, material replaceability, and potential economic shocks. The precise calculation of overall environmental impact reductions and the modelling of their long-term declines fall outside the scope of this thesis and remain a subject for future development. Further research should evaluate the design options of the regulated metric with the design criteria established in subsection 3.4.2.

Further research is necessary to evaluate the precision of using Life Cycle Impact Assessment (LCIA) methods to represent a material's environmental footprint within a pricing system. This includes performing sensitivity analyses to model how single product scores shift when material composition changes, alongside developing methods to verify the data contained within Material Passports. The practical execution of external consumption-based normalisation and its specific mathematical impact on final permit price calculations must be mapped out in future studies. Research is needed to identify the most effective taxation and pricing frameworks (such as price brackets) to translate normalised, weighted environmental values into market-ready permit fees. This includes determining how to weight and integrate non-environmental factors, such as broader societal or public interests into the final permit price calculation.

Because resource caps function as trade barriers, future research must assess the concrete geopolitical and economic impacts of the regulation on international relations, free trade agreements, and global market dynamics. The transition of a resource cap into an active institutional structure requires deeper exploration within political science and public administration. Future studies must focus on how to implement and enforce these powerful limits within strict democratic boundaries to prevent eco-authoritarian risks, ensure multi-stakeholder representation, and maintain administrative transparency. Scholars must continue to investigate the compatibility of absolute resource limits with the developmental potential of individuals, corporations, and states, resolving potential conflicts between planetary boundaries and the societal right to flourish. Future research should explore how to seamlessly integrate the MATS framework with existing international trade mechanisms, such as the current European import duty system.

For any questions about the content of this report, please contact the author Jorian van Bemmelen.

Bibliography

Abbas, Ali (June 2025). "Decoupling economic growth from energy consumption:Review of global trends and policy implications". en. In: *Habitable Planet* 1.1&2, pp. 157–170. ISSN: 3079-5281, 3079-5281. DOI: 10.63335/j.hp.2025.0013. URL: https://www.sciltp.com/journals/hp/articles/2509001593 (visited on 02/17/2026).

Agrawal, Arun et al. (June 2022). "From environmental governance to governance for sustainability". In: *One Earth* 5.6, pp. 615–621. ISSN: 2590-3322. DOI: 10.1016/j.oneear.2022.05.014. URL: https://www.sciencedirect.com/science/article/pii/S259033222200269X (visited on 02/17/2026).

Alcott, Blake (Apr. 2010). "Impact caps: why population, affluence and technology strategies should be abandoned". In: *Journal of Cleaner Production*. Growth, Recession or Degrowth for Sustainability and Equity? 18.6, pp. 552–560. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2009.08.001. URL: https://www.sciencedirect.com/science/article/pii/S095965260900242X (visited on 09/23/2025).

Askham, Cecilia et al. (Dec. 2025). "Review of weighting methods for life cycle impact assessment under GLAM". en. In: *The International Journal of Life Cycle Assessment* 30.12, pp. 2691–2724. ISSN: 1614-7502. DOI: 10.1007/s11367-025-02564-2. URL: https://doi.org/10.1007/s11367-025-02564-2 (visited on 03/17/2026).

Bayer, Patrick and Michaël Aklin (Apr. 2020). "The European Union Emissions Trading System reduced CO2 emissions despite low prices". In: *Proceedings of the National Academy of Sciences* 117.16. Number: 16, pp. 8804–8812. DOI: 10.1073/pnas.1918128117. URL: https://www.pnas.org/doi/10.1073/pnas.1918128117 (visited on 11/02/2023).

Biermann, Frank (2022). "The future of 'environmental' policy in the Anthropocene: time for a paradigm shift". In: *Trajectories in Environmental Politics*. Num Pages: 20. Routledge.

Bjørn, Anders et al. (Nov. 2020). "Life cycle assessment applying planetary and regional boundaries to the process level: a model case study". en. In: *The International Journal of Life Cycle Assessment* 25.11, pp. 2241–2254. ISSN: 1614-7502. DOI: 10.1007/s11367-020-01823-8. URL: https://doi.org/10.1007/s11367-020-01823-8 (visited on 01/22/2026).

Büchs, Milena and Max Koch (2017). *Postgrowth and Wellbeing: Challenges to Sustainable Welfare*. eng. SpringerLink Bücher. Cham: Palgrave Macmillan. ISBN: 978-3-319-59902-1 978-3-319-59903-8. DOI: 10.1007/978-3-319-59903-8.

Cerkini, Bashkim, Roberta Bajrami, and Kaltrina Bajraktari (Nov. 2025). "Relative and Absolute Decoupling: Conceptual Confusions, Policy Consequences, and a Multi-Level Synthesis". en. In: *Economies* 13.11. ISSN: 2227-7099. DOI: 10.3390/economies13110336. URL: https://www.mdpi.com/2227-7099/13/11/336 (visited on 02/17/2026).

Chigbu, Uchendu Eugene, Sulaiman Olusegun Atiku, and Cherley C. Du Plessis (Jan. 2023). "The Science of Literature Reviews: Searching, Identifying, Selecting, and Synthesising". en. In: *Publications* 11.1. ISSN: 2304-6775. DOI: 10.3390/publications11010002. URL: https://www.mdpi.com/2304-6775/11/1/2 (visited on 04/23/2026).

Dalhammar, Carl (Oct. 2019). "It is never too late to give up, or is it? Revisiting policies for sustainable consumption". eng. In: *A Research Agenda for Sustainable Consumption Governance*.

Section: A Research Agenda for Sustainable Consumption Governance. Edward Elgar Publishing, pp. 137–155. ISBN: 978-1-78811-781-4. URL: https://www.elgaronline.com/edcollchap-oa/book/9781788117814/book-part-9781788117814-19.xml (visited on 05/28/2026).

Daly, Herman E. (1974). "Steady-State Economics versus Growthmania: A Critique of the Orthodox Conceptions of Growth, Wants, Scarcity, and Efficiency". In: *Policy Sciences* 5.2, pp. 149–167. ISSN: 0032-2687. URL: https://www.jstor.org/stable/4603736 (visited on 05/06/2026).

De Bruijn, Hans et al., eds. (2002). *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards*. en. Vol. 7. Eco-Efficiency in Industry and Science. Dordrecht: Springer Netherlands. ISBN: 978-1-4020-0228-1 978-0-306-48055-3. DOI: 10.1007/0-306-48055-7. URL: http://link.springer.com/10.1007/0-306-48055-7 (visited on 11/28/2024).

De Laurentiis, Valeria et al. (Oct. 2023). "Exploring alternative normalization approaches for life cycle assessment". en. In: *The International Journal of Life Cycle Assessment* 28.10, pp. 1382–1399. ISSN: 1614-7502. DOI: 10.1007/s11367-023-02188-4. URL: https://doi.org/10.1007/s11367-023-02188-4 (visited on 03/19/2026).

Ecoinvent (2026). *Ecoinvent Database*. en-US. URL: https://ecoinvent.org/database/ (visited on 04/14/2026).

Ekins, Paul et al. (2014). "Reducing Resource Consumption – A Proposal for Global Resource and Environmental Policy". en. In: *Factor X: Policy, Strategies and Instruments for a Sustainable Resource Use*. Ed. by Michael Angrick, Andreas Burger, and Harry Lehmann. Dordrecht: Springer Netherlands, pp. 249–273. ISBN: 978-94-007-5706-6. DOI: 10.1007/978-94-007-5706-6_14. URL: https://doi.org/10.1007/978-94-007-5706-6_14 (visited on 09/08/2025).

Emissieautoriteit, Nederlandse (May 2025). *Home | Nederlandse Emissieautoriteit*. nl. webpagina. Last Modified: 2026-04-17T14:12:01.343Z. URL: https://www.emissieautoriteit.nl (visited on 05/07/2026).

European Academies Science Advisory Council (2024). "Increasing Urgency for Transformative Change". en. In: *ISBN*. DOI: 10.1553/EASAC_Commentary_Transformative_2025. URL: https://austriaca.at?arp=0x0040187a (visited on 11/27/2025).

European Commission (2020). *Circular economy action plan - European Commission*. en. URL: https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en (visited on 12/14/2023).

– (July 2021). *The European Green Deal - European Commission*. en. URL: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (visited on 02/26/2024).

– (Jan. 2026a). *EU-Mercosur*. en. URL: https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/mercosur/eu-mercosur-agreement_en (visited on 04/24/2026).

– (2026b). *The Combined Nomenclature - Taxation and Customs Union*. en. URL: https://taxation-customs.ec.europa.eu/customs/customs-tariff/combined-nomenclature_en (visited on 02/23/2026).

European Environment Agency (Sept. 1999). *Environmental indicators:Typology and overview*. en. URL: https://www.eea.europa.eu/en/analysis/publications/tec25 (visited on 06/05/2026).

– (Dec. 2023). *European Union 8th Environment Action Programme*. en. URL: https://www.eea.europa.eu/en/analysis/publications/european-union-8th-environment-action-programme (visited on 12/09/2025).

– (Mar. 2024). *Accelerating the circular economy in Europe*. en. URL: https://www.eea.europa.eu/en/analysis/publications/accelerating-the-circular-economy (visited on 09/26/2025).

– (Nov. 2025). *Europe's material footprint*. en. URL: https://www.eea.europa.eu/en/analysis/indicators/europes-material-footprint (visited on 11/05/2025).

European Environmental Bureau (Mar. 2024). *A resilient and resource-wise Europe: Sufficency at the heart of the eus future - Google Search*. URL: https://eeb.org/library/a-resilient-

and-resource-wise-europe-sufficency-at-the-heart-of-the-eus-future/ (visited on 08/29/2025).

Eurostat (2025). *Glossary:Direct material input (DMI)*. en. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Direct_material_input_(DMI) (visited on 12/09/2025).

– (2026). *Easy Comext*. URL: https://ec.europa.eu/eurostat/comext/newxtweb/ (visited on 04/16/2026).

Frigg, Roman and Stephan Hartmann (2018). "Models in Science". In: *The Stanford Encyclopedia of Philosophy*. Ed. by Edward N. Zalta. Summer 2018. Metaphysics Research Lab, Stanford University. URL: https://plato.stanford.edu/archives/sum2018/entries/models-science/ (visited on 12/29/2018).

Ginga, Clarence P., Jason Maximino C. Ongpeng, and Ma Klarissa M. Daly (Jan. 2020). "Circular Economy on Construction and Demolition Waste: A Literature Review on Material Recovery and Production". en. In: *Materials* 13.13. Number: 13, p. 2970. ISSN: 1996-1944. DOI: 10.3390/ma13132970. URL: https://www.mdpi.com/1996-1944/13/13/2970 (visited on 01/12/2024).

González De Molina, Manuel and Víctor M. Toledo (2023). *The Social Metabolism: A Socio-Ecological Theory of Historical Change*. en. Vol. 14. Environmental History. Cham: Springer International Publishing. ISBN: 978-3-031-48410-0 978-3-031-48411-7. DOI: 10.1007/978-3-031-48411-7. URL: https://link.springer.com/10.1007/978-3-031-48411-7 (visited on 05/11/2026).

Gorman, Hugh S. and Barry D. Solomon (July 2002). "The Origins and Practice of Emissions Trading". en. In: *Journal of Policy History* 14.3, pp. 293–320. ISSN: 1528-4190, 0898-0306. DOI: 10.1353/jph.2002.0015. URL: https://www.cambridge.org/core/journals/journal-of-policy-history/article/origins-and-practice-of-emissions-trading/7CFD01EF9F489B9BE7516D63E3 (visited on 09/09/2025).

Grant, Maria J. and Andrew Booth (2009). "A typology of reviews: an analysis of 14 review types and associated methodologies". en. In: *Health Information & Libraries Journal* 26.2. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1471-1842.2009.00848.x, pp. 91–108. ISSN: 1471-1842. DOI: 10.1111/j.1471-1842.2009.00848.x. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1471-1842.2009.00848.x (visited on 04/23/2026).

Guinée, Jeroen B., Arjan de Koning, and Reinout Heijungs (2022). "Life cycle assessment-based Absolute Environmental Sustainability Assessment is also relative". en. In: *Journal of Industrial Ecology* 26.3. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/jiec.13260, pp. 673–682. ISSN: 1530-9290. DOI: 10.1111/jiec.13260. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.13260 (visited on 03/19/2026).

Haberl, Helmut et al. (June 2020). "A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights". en. In: *Environmental Research Letters* 15.6, p. 065003. ISSN: 1748-9326. DOI: 10.1088/1748-9326/ab842a. URL: https://doi.org/10.1088/1748-9326/ab842a (visited on 10/13/2025).

Harrigan, James (2003). "Introduction". en. In: *Handbook of International Trade*. _eprint: https://onlinelibrary.wi John Wiley & Sons, Ltd, pp. 1–2. ISBN: 978-0-470-75646-1. DOI: 10.1002/9780470756461.ch. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/9780470756461.ch (visited on 05/07/2026).

Hickel, Jason and Giorgos Kallis (June 2020). "Is Green Growth Possible?" In: *New Political Economy* 25.4. _eprint: https://doi.org/10.1080/13563467.2019.1598964, pp. 469–486. ISSN: 1356-3467. DOI: 10.1080/13563467.2019.1598964. URL: https://doi.org/10.1080/13563467.2019.1598964 (visited on 02/13/2026).

Hickel, Jason et al. (Apr. 2022). "National responsibility for ecological breakdown: a fair-shares assessment of resource use, 1970–2017". In: *The Lancet Planetary Health* 6.4, e342–e349. ISSN: 2542-5196. DOI: 10.1016/S2542-5196(22)00044-4. URL: https://www.sciencedirect.com/science/article/pii/S2542519622000444 (visited on 12/09/2025).

Howlett, Michael (Sept. 2014). "From the 'old' to the 'new' policy design: design thinking beyond markets and collaborative governance". en. In: *Policy Sciences* 47.3, pp. 187–207. ISSN: 1573-0891. DOI: 10.1007/s11077-014-9199-0. URL: https://doi.org/10.1007/s11077-014-9199-0 (visited on 01/27/2026).

– (Dec. 2023). *Designing Public Policies: Principles and Instruments*. 3rd ed. London: Routledge. ISBN: 978-1-003-34343-1. DOI: 10.4324/9781003343431.

International Institute for Sustainable Development (Apr. 2005). *Summary report 23–29 March 2005*. en. URL: https://enb.iisd.org/events/5th-ministerial-conference-environment-and-development-asia-and-pacific-mced-2005/summary (visited on 11/12/2025).

Itsubo, Norihiro (2015). "Weighting - LCA Compendium – The Complete World of Life Cycle Assessment". en. In: *Life Cycle Impact Assessment*. Ed. by Michael Z. Hauschild and Mark A.J. Huijbregts. Dordrecht: Springer Netherlands, pp. 301–330. ISBN: 978-94-017-9744-3. DOI: 10.1007/978-94-017-9744-3_15. URL: https://doi.org/10.1007/978-94-017-9744-3_15 (visited on 10/21/2025).

Kallis, Giorgos and Joan Martinez-Alier (Nov. 2010). "Caps yes, but how? A response to Alcott". In: *Journal of Cleaner Production* 18.15, pp. 1570–1573. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2010.06.010. URL: https://www.sciencedirect.com/science/article/pii/S0959652610002222 (visited on 09/23/2025).

Kallis, Giorgos et al. (Jan. 2025). "Post-growth: the science of wellbeing within planetary boundaries". In: *The Lancet Planetary Health* 9.1, e62–e78. ISSN: 2542-5196. DOI: 10.1016/S2542-5196(24)00310-3. URL: https://www.sciencedirect.com/science/article/pii/S2542519624003103 (visited on 02/17/2026).

Kelly, Adam (Jan. 2024). "A panacea to unsustainable consumption? A review of resource caps". en. In: *Global Sustainability* 7, e18. ISSN: 2059-4798. DOI: 10.1017/sus.2024.16. URL: https://www.cambridge.org/core/journals/global-sustainability/article/panacea-to-unsustainable-consumption-a-review-of-resource-caps/7C1D067BBFCEE171518B6A92E29D0B9C (visited on 08/29/2025).

Kitzmann, Niklas et al. (Sept. 2025). "Planetary Health Check 2025: A Scientific Assessment of the State of the Planet". eng. In: DOI: 10.48485/pik.2025.017. URL: https://planetaryhealthcheck.org/ (visited on 04/24/2026).

Klossek, Polina, Jakob Kullik, and Karl Gerald van den Boogaart (Dec. 2016). "A systemic approach to the problems of the rare earth market". In: *Resources Policy* 50, pp. 131–140. ISSN: 0301-4207. DOI: 10.1016/j.resourpol.2016.09.005. URL: https://www.sciencedirect.com/science/article/pii/S030142071630126X (visited on 05/07/2026).

Koch, Max (Jan. 2020). "The state in the transformation to a sustainable postgrowth economy". In: *Environmental Politics* 29.1. _eprint: https://doi.org/10.1080/09644016.2019.1684738, pp. 115–133. ISSN: 0964-4016. DOI: 10.1080/09644016.2019.1684738. URL: https://doi.org/10.1080/09644016.2019.1684738 (visited on 02/17/2026).

Koch, Max and Hubert Buch-Hansen (Oct. 2021). "In search of a political economy of the post-growth era". In: *Globalizations* 18.7. _eprint: https://doi.org/10.1080/14747731.2020.1807837, pp. 1219–1229. ISSN: 1474-7731. DOI: 10.1080/14747731.2020.1807837. URL: https://doi.org/10.1080/14747731.2020.1807837 (visited on 02/17/2026).

Koninkrijksrelaties, Ministerie van Binnenlandse Zaken en (May 2026). *Kaderwet zelfstandige bestuursorganen*. nl. wet. Last Modified: 2026-05-02. URL: https://wetten.overheid.nl/BWBR0020495/2022-07-01 (visited on 05/05/2026).

Kraus, Sascha et al. (Nov. 2022). "Literature reviews as independent studies: guidelines for academic practice". en. In: *Review of Managerial Science* 16.8, pp. 2577–2595. ISSN: 1863-6691. DOI: 10.1007/s11846-022-00588-8. URL: https://doi.org/10.1007/s11846-022-00588-8 (visited on 04/23/2026).

Krausmann, Fridolin et al. (Aug. 2009). "Growth in global materials use, GDP and population during the 20th century". In: *Ecological Economics* 68.10, pp. 2696–2705. ISSN: 0921-8009. DOI:

10.1016/j.ecolecon.2009.05.007. URL: https://www.sciencedirect.com/science/article/pii/S0921800909002158 (visited on 09/29/2025).

Köhler, Jonathan et al. (June 2019). "An agenda for sustainability transitions research: State of the art and future directions". In: *Environmental Innovation and Societal Transitions* 31, pp. 1–32. ISSN: 2210-4224. DOI: 10.1016/j.eist.2019.01.004. URL: https://www.sciencedirect.com/science/article/pii/S2210422418303332 (visited on 02/17/2026).

Laurent, Alexis and Michael Z. Hauschild (2015). "Normalisation - LCA Compendium – The Complete World of Life Cycle Assessment". en. In: *Life Cycle Impact Assessment*. Ed. by Michael Z. Hauschild and Mark A.J. Huijbregts. Dordrecht: Springer Netherlands, pp. 271–300. ISBN: 978-94-017-9744-3. DOI: 10.1007/978-94-017-9744-3_14. URL: https://doi.org/10.1007/978-94-017-9744-3_14 (visited on 05/11/2026).

Lettenmeier, Michael, Christa Liedtke, and Holger Rohn (Sept. 2014). "Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland". en. In: *Resources* 3.3, pp. 488–515. ISSN: 2079-9276. DOI: 10.3390/resources3030488. URL: https://www.mdpi.com/2079-9276/3/3/488 (visited on 09/23/2025).

Loorbach, D (2017). *Sustainability Transitions Research: Transforming Science and Practice for Societal Change*. nl. URL: https://drift.eur.nl/publications/sustainability-transitions-research-transforming-science-and-practice-for-societal-change/ (visited on 01/09/2024).

L'Haridon, Jacques et al. (Sept. 2023). "SPOT: A Strategic Life-Cycle-Assessment-Based Methodology and Tool for Cosmetic Product Eco-Design". en. In: *Sustainability* 15.19. Company: Multidisciplinary Digital Publishing Institute Distributor: Multidisciplinary Digital Publishing Institute Institution: Multidisciplinary Digital Publishing Institute Label: Multidisciplinary Digital Publishing Institute. ISSN: 2071-1050. DOI: 10.3390/su151914321. URL: https://www.mdpi.com/2071-1050/15/19/14321 (visited on 12/11/2025).

Malinauskaite, Jurgita (2024). *Circular economy: Policies to drive sustainability and the measures to improve energy efficiency*. en-US. DOI: 10.1016/B978-0-443-18454-3.00002-3. URL: https://www.sciencedirect.com/science/chapter/monograph/abs/pii/B9780443184543000023 (visited on 04/24/2026).

Massuga, Flavia et al. (2024). "Modes of governance for sustainability transitions: Conceptual definitions". en. In: *Environmental Policy and Governance* 34.6. _eprint: https://onlinelibrary.wiley.com/doi/p pp. 663–678. ISSN: 1756-9338. DOI: 10.1002/eet.2115. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/eet.2115 (visited on 02/17/2026).

MaterialFlows.net (2025). *Data Visualisations – materialflows.net*. en-US. URL: https://www.materialflows.net/visualisation-centre/data-visualisations/ (visited on 10/29/2025).

Materials & Consumption Taskforce, The Club of Rome, and Hot or Cool (2025). *Securing Europe's future through a just and competitive circular economy*. en-GB. URL: https://www.clubofrome.org/publication/taskforce-europes-future-circular-economy/ (visited on 11/27/2025).

Meysner, Agata, Tim Gore, and IEEP (Sept. 2022). *Towards resource consumption within planetary boundaries*. en-GB. URL: https://ieep.eu/publications/towards-resource-consumption-within-planetary-boundaries/ (visited on 09/22/2025).

Morgan, Bronwen and Karen Yeung (2007). *An Introduction to Law and Regulation: Text and Materials*. Law in Context. Cambridge: Cambridge University Press. ISBN: 978-0-521-68565-8. DOI: 10.1017/CBO9780511801112. URL: https://www.cambridge.org/core/books/an-introduction-to-law-and-regulation/C77EF24DFCF555CDE19AF6B60BE51025 (visited on 01/27/2026).

OECD (Sept. 2001). *OECD Forum 2001: Sustainable Development and the New Economy*. en. URL: https://www.oecd.org/en/publications/oecd-forum-2001-sustainable-development-and-the-new-economy_9789264184824-en.html (visited on 11/12/2025).

OECD (Feb. 2019). *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*. en. OECD. ISBN: 978-92-64-30744-5 978-92-64-30745-2. DOI: 10.1787/9789264307452-en. URL: https://www.oecd.org/en/publications/global-material-resources-outlook-to-2060_9789264307452-en.html (visited on 09/26/2025).

– (2025). *Material consumption - Domestic Material Consumption DMC*. en. URL: https://www.oecd.org/en/data/indicators/material-consumption.html (visited on 12/09/2025).

Otero, Iago et al. (2020). "Biodiversity policy beyond economic growth". en. In: *Conservation Letters* 13.4. _eprint: https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1111/conl.12713, e12713. ISSN: 1755-263X. DOI: 10.1111/conl.12713. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/conl.12713 (visited on 02/17/2026).

OVAM and institute (2024). *The missing piece of the EU Green Deal - Making the case for an EU resources law*. en-GB. URL: https://ieep.eu/publications/making-the-case-for-an-eu-resources-law/ (visited on 11/27/2025).

O'Neill, Daniel W. et al. (Feb. 2018). "A good life for all within planetary boundaries". en. In: *Nature Sustainability* 1.2. Number: 2, pp. 88–95. ISSN: 2398-9629. DOI: 10.1038/s41893-018-0021-4. URL: https://www.nature.com/articles/s41893-018-0021-4 (visited on 11/02/2023).

Pao, Hsiao-Tien and Chun-Chih Chen (Jan. 2019). "Decoupling strategies: CO2 emissions, energy resources, and economic growth in the Group of Twenty". In: *Journal of Cleaner Production* 206, pp. 907–919. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2018.09.190. URL: https://www.sciencedirect.com/science/article/pii/S0959652618329238 (visited on 02/17/2026).

Parrique, Timothée, Jonathan Barth, and François Briens (2019). *Decoupling debunked – Evidence and arguments against green growth as a sole strategy for sustainability*. en-US. URL: https://eeb.org/library/decoupling-debunked/ (visited on 03/17/2025).

Patterson, James et al. (Sept. 2017). "Exploring the governance and politics of transformations towards sustainability". In: *Environmental Innovation and Societal Transitions* 24, pp. 1–16. ISSN: 2210-4224. DOI: 10.1016/j.eist.2016.09.001. URL: https://www.sciencedirect.com/science/article/pii/S2210422416300843 (visited on 02/17/2026).

Paulillo, Andrea and Esther Sanyé-Mengual (Sept. 2024). "Approaches to incorporate Planetary Boundaries in Life Cycle Assessment: A critical review". In: *Resources, Environment and Sustainability* 17, p. 100169. ISSN: 2666-9161. DOI: 10.1016/j.resenv.2024.100169. URL: https://www.sciencedirect.com/science/article/pii/S2666916124000227 (visited on 12/15/2025).

Perthuis, Christian de and Raphael Trotignon (Dec. 2014). "Governance of CO2 markets: Lessons from the EU ETS". In: *Energy Policy* 75, pp. 100–106. ISSN: 0301-4215. DOI: 10.1016/j.enpol.2014.05.033. URL: https://www.sciencedirect.com/science/article/pii/S0301421514003322 (visited on 03/24/2026).

Raworth, Kate (2017). *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*. en. Google-Books-ID: 7A4lDgAAQBAJ. Chelsea Green Publishing. ISBN: 978-1-60358-674-0.

Rockström, Johan et al. (Nov. 2009). "Planetary Boundaries: Exploring the Safe Operating Space for Humanity". en. In: *Ecology and Society* 14.2. ISSN: 1708-3087. DOI: 10.5751/ES-03180-140232. URL: https://www.ecologyandsociety.org/vol14/iss2/art32/ (visited on 12/09/2025).

Rogge, Karoline S. and Kristin Reichardt (Oct. 2016). "Policy mixes for sustainability transitions: An extended concept and framework for analysis". In: *Research Policy* 45.8, pp. 1620–1635. ISSN: 0048-7333. DOI: 10.1016/j.respol.2016.04.004. URL: https://www.sciencedirect.com/science/article/pii/S0048733316300506 (visited on 01/12/2024).

Sala, Serenella et al. (Sept. 2020). "Environmental sustainability of European production and consumption assessed against planetary boundaries". In: *Journal of Environmental Management* 269, p. 110686. ISSN: 0301-4797. DOI: 10.1016/j.jenvman.2020.110686. URL: https://www.sciencedirect.com/science/article/pii/S0301479720306186 (visited on 03/19/2026).

Schandl, Heinz et al. (Sept. 2016). "Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions". In: *Journal of Cleaner Production*. Absolute Reductions in Material Throughput, Energy Use and Emissions 132, pp. 45–56. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2015.06.100. URL: https://www.sciencedirect.com/science/article/pii/S0959652615008331 (visited on 02/13/2026).

Schmelzer, Matthias, Andrea Vetter, and Aaron Vansintjan (2022). *The future is degrowth: a guide to a world beyond capitalism*. eng. London New York: Verso. ISBN: 978-1-83976-584-1.

Snyder, Hannah (Nov. 2019). "Literature review as a research methodology: An overview and guidelines". In: *Journal of Business Research* 104, pp. 333–339. ISSN: 0148-2963. DOI: 10.1016/j.jbusres.2019.07.039. URL: https://www.sciencedirect.com/science/article/pii/S0148296319304564 (visited on 04/23/2026).

Steffen, Will et al. (Feb. 2015). "Planetary boundaries: Guiding human development on a changing planet". en. In: *Science* 347.6223, p. 1259855. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.1259855. URL: https://www.science.org/doi/10.1126/science.1259855 (visited on 03/04/2024).

Stockholm Resilience Centre (2025). *Planetary boundaries*. en. text. URL: https://www.stockholmresilience.org/research/planetary-boundaries.html (visited on 04/24/2026).

Svendsen, Gert Tinggaard (Nov. 2003). "How to design greenhouse gas trading in the EU?" en-US. In: *Energy Policy* 31.14, pp. 1531–1539. ISSN: 0301-4215. DOI: 10.1016/S0301-4215(02)00209-4. URL: https://www.sciencedirect.com/science/article/pii/S0301421502002094 (visited on 03/31/2026).

U. N. Environment Programme (Feb. 2024). *Global Resources Outlook 2024 | UNEP - UN Environment Programme*. en. Section: publications. URL: https://www.unep.org/resources/Global-Resource-Outlook-2024 (visited on 12/09/2025).

Vadén, T. et al. (Oct. 2020). "Decoupling for ecological sustainability: A categorisation and review of research literature". In: *Environmental Science & Policy* 112, pp. 236–244. ISSN: 1462-9011. DOI: 10.1016/j.envsci.2020.06.016. URL: https://www.sciencedirect.com/science/article/pii/S1462901120304342 (visited on 02/13/2026).

Vargas-Gonzalez, Marcial et al. (Dec. 2019). "Operational Life Cycle Impact Assessment weighting factors based on Planetary Boundaries: Applied to cosmetic products". In: *Ecological Indicators* 107, p. 105498. ISSN: 1470-160X. DOI: 10.1016/j.ecolind.2019.105498. URL: https://www.sciencedirect.com/science/article/pii/S1470160X19304832 (visited on 12/11/2025).

Voet, Ester van der, Lauran van Oers, and Igor Nikolic (2004). "Dematerialization: Not Just a Matter of Weight". en. In: *Journal of Industrial Ecology* 8.4. _eprint: https://onlinelibrary.wiley.com/doi/pdf/ pp. 121–137. ISSN: 1530-9290. DOI: 10.1162/1088198043630432. URL: https://onlinelibrary.wiley.com/doi/abs/10.1162/1088198043630432 (visited on 10/29/2025).

Vollebergh, Herman R. J. and Corjan Brink (2020). *What Can We Learn from EU ETS?* eng. Working Paper 8236. CESifo Working Paper. URL: https://www.econstor.eu/handle/10419/216632 (visited on 03/24/2026).

Vázquez, Daniel et al. (Dec. 2023). "Level of decoupling between economic growth and environmental pressure on Earth-system processes". In: *Sustainable Production and Consumption* 43, pp. 217–229. ISSN: 2352-5509. DOI: 10.1016/j.spc.2023.11.001. URL: https://www.sciencedirect.com/science/article/pii/S2352550923002531 (visited on 02/17/2026).

Wiedmann, Thomas O. et al. (May 2015). "The material footprint of nations". In: *Proceedings of the National Academy of Sciences* 112.20, pp. 6271–6276. DOI: 10.1073/pnas.1220362110. URL: https://www.pnas.org/doi/10.1073/pnas.1220362110 (visited on 09/22/2025).

Xiao, Yu and Maria Watson (Mar. 2019). "Guidance on Conducting a Systematic Literature Review". en. In: *Journal of Planning Education and Research* 39.1, pp. 93–112. ISSN: 0739-456X, 1552-6577. DOI: 10.1177/0739456X17723971. URL: https://journals.sagepub.com/doi/10.1177/0739456X17723971 (visited on 05/26/2026).

Zero Waste Europe (Jan. 2024). *Sustainable resource management in the EU - White paper for an EU within planetary boundaries*. en-GB. URL: https://zerowasteeurope.eu/library/sustainable-resource-management-eu/ (visited on 08/29/2025).