Climate Adaptation Investments Through The European Structural Economy

Macroeconomic Assessment Using Multi Region Input-Output Analysis

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Extensive Summary

Public investments in Climate Change Adaptation (CCA) are progressing, and the private sector is being increasingly mobilised; however, prioritising CCA efforts remains complex. Public efforts to mobilise private CCA have already been implemented with observable impacts. Yet, the justification and prioritisation of such investments remain a key challenge due to the scarcity of resources and the often long-term, uncertain nature of CCA benefits. As a result, pivotal institutions are now turning to multi-criteria assessment to support decision-making by capturing multiple benefits of CCA investments. Among these, the *Triple Dividend of Resilience* framework stands out for incorporating economic and co-development benefits, alongside risk reduction and social co-benefits.

Despite growing recognition of multiple CCA benefits, the macroeconomic dividend of CCA remains one of the least understood, representing a persistent gap in current research. Most of the research that tries to capture the economic benefits of CCA investments remains anecdotal. Case studies have highlighted how various CCA efforts can enhance local economic activity, stimulate productivity, or reduce background risk. However, to date, there is no large-sample, quantitative analysis that systematically measures the economy-wide benefits of CCA across hazards, countries and sectors. This is mainly due to the absence of large-sample quantitative CCA data. As a result, much remains unknown about the systemic economic impacts of CCA investments. This gap is critical given that studies have found that the economic and social co-benefits often deliver the greatest overall benefits, even more so than avoided losses.

This study provides the first quantitative macroeconomic assessment of CCA using a Multi-Region Input Output (MRIO) model to map the output and value-added effects of CCA investments that flow through the European economy. The MRIO model is based on final European adaptation demand categorised by climate hazards, across EU countries, purchasing, and supplying sectors [Howard et al., 2020]. Backwards linkages follow the trade flow patterns of the EU general economy (from the FIGARO database) and are consequently stress-tested using a Global Sensitivity Analysis. The model distinguishes public and private CCA channels to identify their unique propagation through the economic system. The MRIO model is used for three key purposes: (1) to track total output of EU sectors and countries induced by CCA investments and identify pivotal sectors (2) to trace how value added is distributed across countries and sectors and thereby shedding light on the Global Value Chain structures, and (3) to develop a metric for assessing the macroeconomic return from CCA investments.

Key findings reveal pivotal sectors, sectoral - and national value added allocation, distinct Global Value Chain characteristics, and economic return metrics that can enhance CCA prioritisation. With respect to output, the most pivotal sectors for supplying CCA goods are water & waste management, manufacturing, and professional services. These sectors are central to adaptation-related activity and frequently embedded in broader supply chains. In terms of value-added distribution, adaptation-related Global Value Chains appear more domestically sourced than traditional economic flows. This indicates stronger national-level embeddedness of adaptation investments, potentially increasing localised co-benefits. The macroeconomic return metric shows that returns on adaptation investments vary widely across countries and sectors. Yet in many cases, these short-term returns are in the same range as general EU economic investments, confirming the earlier-mentioned notion that CCA creates value beyond avoided losses.

Policy recommendations derived from the MRIO analysis are multifaceted; this study specifically highlights 3 key policy directions. First, this study identifies critical sectors that can be targeted for industrial policies. Secondly, spillover effects from CCA investments are found to be modest and diffuse, which likely complicates the initiation of solidarity funding schemes across Europe. Therefore, it seems more fruitful to explore bilateral funding schemes or additional side-payments, rather than pursuing systematic EU-wide solidarity schemes. This becomes even more urgent after IPCC's warning that climate change is likely to widen economic disparities across Europe. Lastly, this study proposes a criterion to assess the short-term macroeconomic return of CCA investments. This criterion offers the possibility to assess the macroeconomic dimension of CCA investments. Quantifying detailed macroeconomic returns can contribute as an additional objective to either static multi-criteria assessments or dynamic multi-objective assessments.

This study faces several limitations, primarily related to data availability and sectoral resolution. National-level adaptation data remain scarce, requiring the use of a uniform European spending pattern. The sectoral aggregation used, while suitable for high-level analysis, masks important variation, particularly in manufacturing and water & waste management. More granular data on investment flows and hazard-specific products would improve value-added estimates and support targeted industrial policy. Additionally, the study focused exclusively on public expenditure and did not include fiscal instruments, such as subsidies or tax incentives.

Future research should prioritise the quantification of decision-making criteria under uncertainty and a deeper quantitative analysis of public-private dynamics. While this study captures macroeconomic co-benefits, these reflect only part of adaptation's broader value. Further work should quantify additional economic objectives, such as productivity gains, local investment, and Foreign Direct Investment linked to risk reduction. These additional criteria can support more robust, multi-objective decision-making and support prioritising CCA efforts. Research should also assess the effectiveness of public CCA strategies to support prioritisation based on cost and impact, and to better understand how these strategies influence private sector engagement.

Acknowledgements

Dear Reader,

Before you start, I would like to take a short moment of your time to thank the people who made this thesis possible.

In November 2024, I reached out to Tatiana Filatova about the potential of doing a thesis project under her supervision, centred around climate change adaptation. During the first meetings, me from South Korea and Tatiana and Ignasi from TU Delft, it became clear I had a wide range of thesis directions to choose from. The project was wide open, on the one hand very exciting and full of possibilities, on the other hand quite overwhelming if you are not very familiar with the field.

I want to thank Tatiana and Ignasi for guiding me through this climate change adaptation field, providing me with interesting directions and also for keeping me on the right track. Not only at the beginning of the project, but throughout the entire thesis, your expertise, critical questions, and writing experiences, and of course, your support helped me structure my thoughts. A special thanks to Ignasi as well, for all the more informal but always valuable Monday catch-ups, and of course, the talks after the process meetings. I'm very grateful to both Tatiana and Ignasi for your support!

My thanks also go to my second supervisor, Servaas Storm, first of all for all your engaging courses and, of course, your book, but mostly for your personal support on the economic methods during this project.

Nine months later, I can say I've scratched the surface of the complexity of climate change adaptation, have been introduced to the basics of multi-regional input-output analysis, and have learned the most about what it takes to write a thesis.

Thanks!

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Acronyms

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1 Introduction

Effective climate strategies require both Climate Change Mitigation (CCM) and Climate Change Adaptation (CCA). Without mitigation efforts, adaptation costs will rise substantially as the impacts of climate change worsen [IPCC, 2023]. However, even with ambitious CCM policies, CCA remains necessary, as many climate risks are already locked in. Due to historical and present emissions, global temperatures will continue to rise, leading to more frequent extreme events and shifting climate patterns [IPCC, 2023].

In recent years, CCA has received increasing recognition as a complementary activity alongside CCM. For instance, the public CCA efforts have been steadily growing, with governments funding adaptation programs and initiating adaptation projects to build societal-wide climate resilience [CPI, 2024]. Recently, attention has shifted to the role of the private sector — referring to businesses and industries and excluding households — in contributing to CCA. Precise data on private CCA remain scarce due to limited disclosure, inconsistent reporting, and classification challenges, yet the available evidence suggests that private sector engagement in adaptation is still relatively low but is showing signs of growth, particularly in Europe [CPI, 2024; United Nations Environment Programme, 2022; Cortés Arbués et al., 2025]. Nonetheless, the private sector is increasingly recognised as essential in complementing the constrained public resources [Climate Investment Funds, 2016; World Bank Group, 2021]. Beyond financial contributions, businesses can play a critical role in addressing sector- and location-specific climate risks, and in driving innovation for resilience [Agrawala et al., 2011]. Cochu et al. highlighted three distinct roles for the private sector to advance their CCA [Cochu et al., 2019]. First, **autonomous private adaptation**, which can be defined as: adaptation initiated by private companies, due to rational self-interest, that enhances their own climate resilience. This is the first and most notable responsibility entrusted to the private sector. However, focusing exclusively on autonomous private adaptation overlooks a significant public dimension that is entrusted to the private sector. This public dimension is captured in the second role, **adaptation services**: the responsibility to provide innovative adaptation solutions, goods or services to other actors. The final role, **capital provision**, refers to the responsibility of supplying financial capital for large-scale public adaptation efforts.

To better understand how these three private roles are put into practice, I would like to revisit foundational economic arguments. At the roots of CCA discussions, scholars argued that there should only be efficient adaptation. Efficient adaptation implies that the marginal costs of adaptation are less than the marginal benefits [Mendelsohn, 2012]. Private adaptation will therefore only evolve in the most vulnerable sectors or regions [Mendelsohn, 2000]. In line with Mendelsohn, Kahn argues that involved actors will follow efficient adaptation if it is in their interest [Kahn, 2016]. Consider farmer A, whose crop yields decline due to prolonged heatwaves. In response, the farmer will invest in adaptation products by purchasing heat-resistant crops. If farmer A chooses not to adapt, another farmer may enter the market and outcompete farmer A. In line with this Schumpeterian economic thought, adaptation is therefore expected to emerge autonomously through innovation and development in areas where it is most needed. This example illustrates how market forces, as captured in Mendelsohn and Kahn's ideas, drive the first two roles of private adaptation. The first role, **autonomous private adaptation**, emerges through rational market behaviour. The second role, **adaptation services**, arises from market demand for heat-resistant crops, creating opportunities for entrepreneurs to offer adaptation services. The first two roles assume that adaptation occurs incrementally and is largely reactive among private actors. But most importantly, these two roles do not require public intervention. In contrast, when it comes to the final role, **capital provision for public goods**, the public sector plays a central role. This framework positions the public sector as the primary leader in coordinating and financing joint adaptation efforts [Mendelsohn, 2000]. Public involvement is essential for designing effective adaptation efforts in the most affected societal sectors, such as public health and safety [Chambwera et al., 2014; Massetti and Mendelsohn, 2018].

Although this theory provides a clear framework about private and public CCA, the underlying assumptions were increasingly being questioned. The notion that **autonomous private adaptation** and **adaptation services** are autonomously channelled, without public intervention, has become empirically and theoretically unsupportable. Empirically, the private CCA finance has been lagging, and private actors have not been fulfilling their autonomous adaptation roles [United Nations Environment Programme, 2022; OECD, 2024a]. Theoretically, efficient adaptation presumes perfect information, perfect planning, and coordination, and overlooks the significant uncertainties surrounding climate hazards [Fankhauser and Burton, 2011]. In other words, inevitable market failures undermine Mendelsohn and Kahn's ideas of market efficiency within private CCA [Cimato and Mullan, 2010; Pauw et al., 2022; Frontier Economics, 2022; Stern, 2008]. Although a range of market failures affect CCA—such as the inequitable distributional externality highlighted by Stern [2008]—the market failures that most directly hinder private CCA are imperfect information and coordination. Imperfect information, coming from the uncertainty of climate hazards and the lack of generalisable cost–benefit data, makes it difficult for private actors to assess whether, when, and to what extent adaptation investments will yield returns [Chiabai et al., 2015; Chambwera et al., 2014; European Environment Agency, 2022]. Coordination failures occur when private actors are unable to align their efforts or share the benefits of adaptation, particularly in cases where public CCA needs the private services [Osberghaus et al., 2010]. More specifically, these market failures hinder the first two private roles of **autonomous private adaptation** and **adaptation services**. The public sector can help by minimising these market failures. However, this must be done with caution, as a dominant public role risks crowding out private initiatives and may disrupt the efficient allocation of resources by private actors. It should therefore shift from being the primary investor in CCA towards a facilitator, mobilising private sector engagement in adaptation [Global Commission on Adaptation, 2019; Worldbank Group, 2021].

Public efforts to mobilise private CCA have been implemented and shown their effect. To address the market failure caused by imperfect information, the public sector laid out strategies to fight uncertainty surrounding climate impacts, lack of awareness, and understanding of cost-benefit outcomes [Cimato and Mullan, 2010; Frontier Economics, 2022]. For instance, National Adaptation Strategies (NAS) and National Adaptation Plans (NAP) are developed by governments to support private CCA. In Europe, by the end of 2021, every member state had created a NAS and 22 had operationalised their long-term objectives in their NAP [Climate ADAPT, 2024]. The NAS and NAP in Europe propose targeted policies among the whole domain of CCA [Leitner et al., 2021]. Examples vary among EU member states, including mainstreaming CCA in policies, raising awareness, improving climate risk assessments, and enhancing bureaucratic processes and information sharing [European Environment Agency, 2024b]. Furthermore, to address the market failure of imperfect coordination, finance frameworks and national investment platforms are designed [OECD, 2024a; Worldbank Group, 2021; Werkgroep Klimaatadaptatie, 2023]. Besides, a wide battery of finance instruments (i.e. guarantees, blended finance) has been proposed and implemented, to incentivise private sector participation [OECD, 2024a,b]. Thus, it seems clear that the public is trying to go beyond its traditional role of providing public adaptation goods. Governments and public institutions seek to correct market failures and thereby aim to mobilise private CCA efforts that would otherwise not materialise.

Yet, justifying and prioritising such interventions remains a challenge, particularly since resources remain scarce and the benefits of these interventions are often unobvious, long-term and highly uncertain [Hallegatte et al., 2012; Josephson et al., 2024]. According to the IMF: CCA can expand long-term fiscal space by reducing climate-related damages, but in the short term, it competes with other public spending and seems costly if climate impacts do not occur [Aligishiev et al., 2022]. Especially given the nature of both public and private CCA investments, which often require large upfront costs to protect against distant, low-probability events or long-term shifts in climate patterns [Fankhauser and Burton, 2011; Chambwera et al., 2014]. As a result, most of these CCA interventions are still seen as costs and not as benefits. A framework that has been proposed to justify and prioritise general CCA investments is the Triple Dividend Framework [Tanner et al., 2015]. This framework is based on the foundation that if the benefits of CCA projects are more fully quantified, CCA investments will increase [Heubaum et al., 2022]. So, this framework outlined three dividends of adaptation investments [Tanner et al., 2015]:

1. Avoidance of losses: reducing the direct damages from climate-related hazards, such as infrastructure damage, loss of livelihoods, and human casualties.

2. Economic co-benefits: stimulating economic activity by reducing background risk, encouraging investment, increasing productivity, and supporting innovation and employment.
3. Development co-benefits: generating broader social, environmental, and institutional benefits, such as improved health outcomes, ecosystem restoration, enhanced social cohesion, and strengthened governance structures.

By identifying three dividends, this framework tries to look beyond the benefits of risk avoidance and capture the broader value of CCA. It aims to reduce the impact of climate uncertainty on adaptation decision-making by highlighting that, even in the absence of extreme events, certain investments can still have benefits that outweigh their costs. In fact, a study showed that within adaptation projects, the second and third dividends can be more beneficial than the first dividend [Heubaum et al., 2022].

Therefore, academics and key institutions, such as the IPCC, have proposed prioritising CCA investments based on a Multi Criteria Assessment (MCA) to better account for their multiple benefits [Chambwera et al., 2014; Viguié and Hallegatte, 2012; Pisu et al., 2024]. Similar approaches have been adopted, aligning with the Triple Dividend framework as a form of MCA [OECD, 2024; Global Center on Adaptation, 2024]. These assessments enable the prioritisation of CCA actions that perform well across the three dividends and thus mitigate the impact of climate uncertainty. Furthermore, it has been proposed to apply MCA not only statically, but also within more dynamic decision-making strategies, such as robust decision making, scenario-based planning, or adaptive pathways [Wilby, 2022; Hallegatte et al., 2012; World Bank, 2024]. These dynamic searching strategies are essentially based on MCA; however, they try to optimise the solutions over scenarios or time. For instance, the World Bank proposes to develop adaptation pathways that start implementing no-regret options in the short term and initiate the process of future transformational CCA in the long term [World Bank, 2024]. Additionally, other academics and the IPCC, although not framed as adaptive pathways, suggest that effective adaptation is probably best achieved through a long-term and flexible process that allows for change, learning and adjustment, with early implementation of no-regret options [Chambwera et al., 2014; Hallegatte, 2009]. In order to prioritise adaptation measures, an MCA based on the three dividends can be helpful. It can identify adaptation measures that offer high benefits across the three dividends and should be prioritised. For this to happen, a clear understanding of the actual benefits across the three dividends is essential.

A considerable body of research has focused on the potential gains associated with the first dividend, notably via cost-benefit assessments of disaster risk reduction efforts [Mechler, 2016; Josephson et al., 2024]. In contrast, most of the research on the second dividend, which captures the economic benefits of CCA investments, remains anecdotal. For example, early warning systems have been shown not only to reduce disaster-related damages but also to stimulate productivity and reduce uncertainty for businesses and households [Hallegatte et al., 2012; Rozer et al., 2021]. Case studies have similarly highlighted how ecosystem-based adaptation or improved water management can enhance local economic activity and agricultural yields [Global Commission on Adaptation (GCA), 2021; Tanner et al., 2015]. However, to date, there is no large-sample, quantitative analysis that systematically measures the economy-wide benefits of CCA across hazards, countries and sectors. This is mainly due to the absence of quantitative CCA data, and no explicit focus on the macroeconomic effects of CCA investments. As a result, much remains unknown about the systemic economic impacts of CCA investments. This gap is critical given that, according to Heubaum et al., the second and third dividends often deliver the greatest overall benefits, even more so than avoided losses [Heubaum et al., 2022]. Therefore, this study aims to quantitatively map the macroeconomic effects of CCA investments, distinguished per hazard, across EU countries and sectors. It will not only assess the system-wide effects of these investments, but will also make a distinction between the effects induced by public and private CCA. The main research question is therefore formulated as follows:

> **What are the system-wide macroeconomic impacts of public and private CCA investments across Europe, and how can these insights inform more effective short-term adaptation strategies?**

We will provide an answer to this research question by first identifying how the adaptation streams (e.g. adaptation investments) create total output across Europe. Therefore, the first sub-research question sounds:

1) How have public and private CCA efforts in Europe contributed to total adaptation output across different sectors, countries, and climate hazards?

Afterwards, we translate the total output towards value-added. We will assess how the adaptation output flows through the European structural economy and generate and distribute value added, which will address the second research question:

2) To what extent have the total CCA investments in Europe contributed to value added, and how has this value diffused across national economies and sectors?

If we have quantified the absolute value added generated, we will then evaluate their macroeconomic return by comparing the generated value added to the initial adaptation expenditure, thereby creating a metric that reflects the economic return on adaptation investments. This is captured within the third research question:

3) How do public and private CCA efforts in Europe differ in their contribution to domestic value added across sectors, hazards and countries?

Together, these three sub-questions aim to advance the empirical understanding of adaptation's system-wide economic effects. Aside from a better empirical understanding, the findings will support decision-makers in developing more effective adaptation strategies. This study focuses on three different directions for improving CCA decision making. First, this study can identify pivotal sectors for CCA, offering guidance for targeted industrial or trade policies. Second, this study will illustrate how CCA investments cross borders and may help reopen the discussion on the role of supranational cooperation and co-investment in adaptation [Biesbroek and Swart, 2019; European Environment Agency, 2022]. This study does not directly assess the potential of shared funding mechanisms; it offers a first step in identifying possible economic spillovers from CCA investments. These preliminary insights can help improve the design of CCA funding programs in Europe or support the notion of expanding these funding initiatives. Lastly, understanding the economic co-benefits of CCA investments can give prioritisation based on the second dividend of the Triple Dividend Framework. Adaptation investments that generate greater macroeconomic gains are more likely to qualify as no- or low-regret, as their advantages are realised regardless of how future climate scenarios unfold.

Addressing the main and sub-research questions requires a methodology that is both macro-economically comprehensive and sufficiently granular to trace national and sectoral inter-dependencies within the economy. For this purpose, an Multi-Region Input Output (MRIO) analysis has been selected. MRIO analysis is suitable as it captures the production and trade linkages across countries and sectors, allowing for a detailed mapping of how adaptation investments propagate through the structural economy. This makes it particularly well-suited for assessing the system-wide effects of adaptation streams and for deriving meaningful economic metrics such as value added. While more complex models such as Computable General Equilibrium and Dynamic Stochastic General Equilibrium models are also suitable for assessing macro-economic effects—and are in fact often built upon input–output tables—a first empirical insight can be achieved using MRIO. It provides, in contrast to earlier-mentioned models, a framework that is transparent and can identify the direct and indirect economic impacts of CCA expenditures. Moreover, MRIO-tables possess several properties that align with the objectives of this research. First, MRIO enables the straightforward aggregation of demand and output across sectors and countries, which is used for addressing the first research question. Second, concerning the second research question, MRIO facilitates the use of Global Value Chains (GVC), which illustrates the international fragmentation of production and how value is created and transferred across borders and sectors to meet final demand [Koopman et al., 2014]. Third, relevant to the third research question, MRIO allows for comparing the domestically returned value added to the initial adaptation expenditure.

Contribution

Coming back to the challenge of building a climate-resilient society, this study aims to contribute both theoretically and socially. From the theoretical perspective, this study is the first to apply an MRIO model to assess how adaptation streams propagate through the European economy quantitatively. It offers a novel contribution by tracing adaptation output across hazards, sectors and countries, while simultaneously evaluating their macroeconomic impacts. This macroeconomic perspective

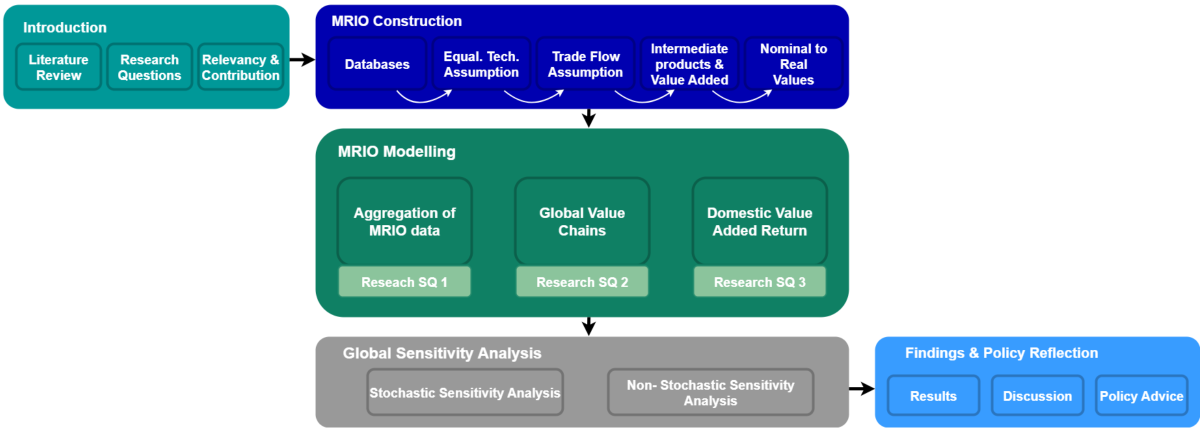

Figure 1.1.: Research Design *(Source: Own illustration)*

is largely absent in current adaptation literature; this study therefore aims to demonstrate the value of integrating macroeconomic analysis into CCA research. From a societal perspective, the findings provide policy-relevant insights to guide more effective adaptation strategies. First, by identifying pivotal sectors that can be targeted for industrial policies. Second, by identifying economic spillovers across countries, this study aims to reopen discussions on EU-level coordination. Third, by identifying high-macroeconomic-return on CCA-investments, this study aims to support the prioritisation of CCA investments.

Report Structure

To get a sense of what lies ahead, the adaptation MRIO-table has to be constructed from the ground up. Given the broad range of methodological steps involved, a clear research design can help provide a structural overview; see Figure 1.1. The design contains 3 essential components. First, the *MRIO Construction* will walk through the crucial steps to construct an adaptation MRIO. After the MRIO is built, within the component of *MRIO Modelling*, three MRIO properties are applied to answer each research sub-question. Finally, component 3 includes a *Global Sensitivity Analysis (GSA)*.

Before introducing the four key methodological components, this report first discusses the technical properties and suitability of the MRIO model in **Chapter 2**. After having established MRIO's suitability, the research will be conceptualised in **Chapter 3**. This chapter will walk through the four key components mentioned earlier. The aim is to situate the methodologies within the broader academic context and to explain the reasoning behind key methodological choices. Within **Chapter 4**, the results of the MRIO model are presented, and subsequently discussed in **Chapter 5**. Finally, **Chapter 6** will elaborate on the concluding implications, limitations and recommendations for further research.

2 Multi Region Input-Output Model

This chapter will build on the previous chapter by explaining the essential properties of an MRIO-table and how these properties align with the research questions. First, the state-of-the-art and the range of applications of MRIO models are briefly introduced. Afterwards, the MRIO properties are explained in further detail, focusing on those particularly relevant to this study. Finally, the discussion concludes with a critical reflection on the strengths and relevance of MRIO for addressing the research question, as well as a reflection on its limitations and the underlying assumptions that may constrain its suitability.

2.1. State-of-the-Art

MRIO analysis is a quantitative method used to trace economic activities across different countries and sectors [Leontief, 1986]. It tracks how the output of one sector (e.g., steel) becomes the input of another (e.g., car manufacturing), ultimately reaching final consumers (e.g., households). This quantitative method, known as an Input-Output table, was developed by Nobel Laureate Wassily Leontief in 1936 [Leontief, 1936a]. Walter Isard, back in 1966, came up with the idea to extend the Input-Output table towards multiple regions [Isard, 1966]. The use of MRIO models has expanded significantly in recent years, largely driven by the open-source availability of MRIO datasets such as WIOD and EXIOBASE. [Timmer et al., 2015; Stadler et al., 2021]. These databases have enabled researchers to apply MRIO models across a wide range of domains. In environmental economics, MRIO is now standard practice for tracing carbon footprints along the supply chains. It can assess embodied emissions and inform sustainability policies [Hertwich, 2021; Wiedmann and Minx, 2009]. In trade policy, MRIO models are used to map GVC and quantify cross-border linkages in production and value added [Koopman et al., 2014; Borin and Mancini, 2023; OECD, 2023]. Recent advancements include the use of Structural Path Analysis to decompose supply chain effects and identify critical paths through the economy [Owen et al., 2016; Xie et al., 2020]. Beyond these static MRIO applications, several notable efforts have aimed to make MRIO models dynamic, for instance through a temporal Leontief inverse [Avelino et al., 2021]. These dynamic MRIO-models can then be used to capture macroeconomic developments and structural changes over time [Kratena and Temursho, 2017; Chen et al., 2023]. Lastly, MRIO tables are nowadays not only used as standalone models, but they also form the basis for more advanced economic policy models such as CGE and DSGE.

2.2. Technical Properties of MRIO

A demand-pull MRIO model will be used in this study. This perspective focuses on how **changes in final demand** affect the total output of sectors and eventually impact the value added components. Demand-pull MRIO model is the Keynesian version of the MRIO model, where the final demand is exogenous, and is defined by the so-called animal spirits. A demand-pull MRIO-table is illustrated in Figure 2.1. The figure is originally adapted from Li and GE (2022), but has been modified for clarity reasons [Li and Ge, 2022]. The MRIO-table is composed of several matrices and vectors. It consists of the Z-matrix (intermediate products exchanged between industries), the F-matrix (final demand), the V-matrix (value added), the x'-vector (gross input) and the x-vector (gross output). For clarity reasons, right now only one column and one row are shown; however, normally, each industry in each country has one individual column and row. Usually, a MRIO spans over one year, and the values are denoted in transactions.

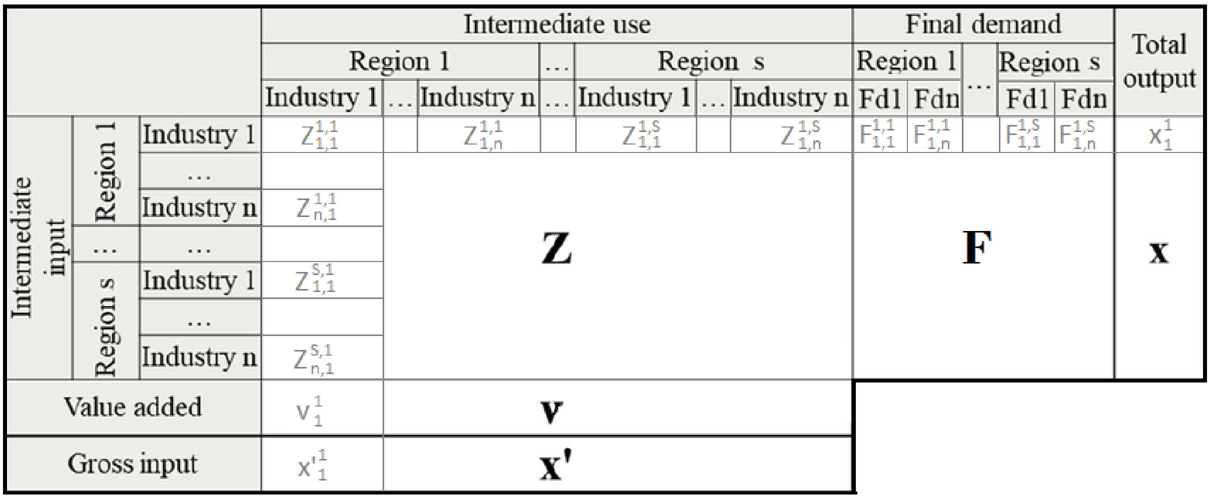

Figure 2.1.: Basic structure of the MRIO table. *(Source: own illustration)*

Property 1: Accounting Principle

A MRIO table can be read in different ways, through the column perspective and the row perspective.

To start with the column-perspective, a column, for instance, the column of Industry 1 in Region 1, shows all inputs used in their production process. Inputs of an industry can be divided into *Production Inputs*, such as steel, energy, construction, and *Payment Inputs* or named from now on *Value Added*, which represent the payments to labour, capital, taxes, and subsidies. Within column 1, the *Production Inputs* needed are denoted within the Z-matrix, and the *Value Added* are denoted in the V-matrix. Formally, *Gross Input* x' can then be described as equation 2.1.

Conversely, the corresponding row details how this industry's output is sold: as intermediate inputs to other industries Z or as final goods to final consumers F, which is summed together as the total output denoted as x. Final demand actors can be (foreign) households, (foreign) capital expenditure of private companies and (foreign) governments. In matrix notation, it is written as equation 2.2:

$$\mathbf{x}' = \mathbf{Zi} + \mathbf{v} \tag{2.1}$$

where:

$$\mathbf{x}' = \begin{bmatrix} x_1'^1 & \dots & x_n'^s \end{bmatrix}$$

$$\mathbf{Zi} = \begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{1,n}^{1,s} \\ \vdots & \ddots & \vdots \\ z_{n,1}^{s,1} & \cdots & z_{n,n}^{s,s} \end{bmatrix}$$

$$\mathbf{v} = \begin{bmatrix} v_1^1 & \dots & v_n^s \end{bmatrix}$$

$$\mathbf{x} = \mathbf{Zi} + \mathbf{F} \tag{2.2}$$

where:

$$\mathbf{x} = \begin{bmatrix} x_1^1 \\ \vdots \\ x_n^s \end{bmatrix}$$

$$\mathbf{Zi} = \begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{1,n}^{1,s} \\ \vdots & \ddots & \vdots \\ z_{n,1}^{s,1} & \cdots & z_{n,n}^{s,s} \end{bmatrix}$$

$$\mathbf{F} = \begin{bmatrix} f_{1,1}^{1,1} & \cdots & f_{1,n}^{1,s} \\ \vdots & \ddots & \vdots \\ f_{n,1}^{s,1} & \cdots & f_{n,n}^{s,s} \end{bmatrix}$$

If we focus on a particular sector n in country s, the fundamental accounting identity implies that the *input side* x' of production must equal the *output side* x.

Property 1: Accounting Principle

In MRIO terminology, this means that the *column* corresponding to sector n in country s —which captures all inputs used by that sector—is equal to the *row* of sector n in country s —which reflects how its output is distributed across other sectors and final demand.

This accounting principle rests on the double-entry bookkeeping, which implies that every unit of expenditure in an economy generates an equal unit of income. Following the accounting principle, and summing over all columns and rows, the MRIO system becomes fully balanced: the total input into the economy equals the total output.

Property 2: GDP

MRIO-table has the ability to compute national or sectoral GDPs [Leontief, 1951]. Since the final demand matrix F consists of governments G, households C and Private Sector I for each country E, and imports M can be deduced from the Z-matrix, the aggregate demand of the whole economy is known. So the GDP extraction is based on the foundations of macroeconomics:

$$Y = C + I + G + (E - M) \tag{2.3}$$

This is the expenditure calculation of the GDP. As we have concluded earlier, the MRIO is balanced, and thus we can retrieve the GDP as well from the income calculation. The income calculation states that GDP is the sum of labour income L plus capital income N, or mathematically:

$$Y = L + N \tag{2.4}$$

The final method for calculating GDP is by summing the value added of all industries.

$$Y = \sum Va_n^s \tag{2.5}$$

With this, the second property of the MRIO table is clear:

Property 2: GDP Computations

A MRIO Table is able to compute the GDP through the (1) expenditure -, (2) income- and (3) output perspective. The GDP, or Value Added, can be determined at the sectoral, country and sector-country levels.

Property 3: Multipliers

A multiplier is a process in which an initial increase in autonomous final demand (such as private investment, government spending, or exports) leads to a greater overall increase in total income (GDP) due to repeated rounds of spending. So an additional euro invested in a particular industry will not only increase production of that industry (direct effect) but will ripple back and also increase production of the input industries (indirect effect). This concept is particularly useful for policy and decision-making, as it helps identify which sectors generate the greatest economic returns from public or private investment. Leontief himself had already invented the basis of computing the multiplier out of the IO table [Leontief, 1936b]. Many more scholars began to focus on the multipliers, and with this, the Type 2 multiplier (including induced effects), employment, or public expenditure multipliers were born [Weiss and Gooding, 1970; Miyazawa and Miyazawa, 1976]. Another valuable type of multiplier is the internal value-added multiplier, which measures the Domestic Value Added (DVA) generation of 1 euro spent [Dietzenbacher and van der Linden, 1997; Miller and Blair, 2009]. Lastly, the weighted average value-added multiplier aggregates value-added effects using final demand expenditures as weights.

Property 3: MRIO Multipliers

A MRIO table is able to extract multipliers. It can extract *Total Output -, Public Expenditure -, Employment -, Value Added -, Type 1- and Type 2 Multipliers*. In addition, it can make a distinction between intra- and extra multipliers, separating the multiplier effect of an investment domestically and globally [Miller and Blair, 2009].

Property 4: Global Value Chains

While property 3 allows us to determine the value-added multiplier by country and sector, it remains unclear who the ultimate consumers of these products are. In other words, we do not know who **induced** this value added. This is where GVC come in. GVC are defined as the cross-border sequence of value-adding activities involved in producing and delivering a good or service [Koopman et al., 2014]. MRIO models are particularly useful for analysing GVC since they capture trade between regions in intermediate goods, helping to identify dependencies between sectors and countries [Baldwin et al., 2012; Johnson, 2018]. GVC enable the identification of a range of value-added metrics, such as DVA and Foreign Value Added (FVA), which can be attributed to either (direct or indirect) domestic or foreign demand, and generated through intermediate or final products.

Property 4: Global Value Chains

GVC are able to break down the value added across sectors and countries to identify who induced it, whether through intermediate demand, final demand, domestically, or via foreign exports [Koopman et al., 2014].

Property 5: Impact Analysis

One final property of the MRIO-table worth mentioning is its use in impact analysis. MRIO models suit the purpose of analysing the effects of targeted changes in specific model parameters, such as a foreign final demand increase. This self-induced shock propagates through the system, affecting intermediate inputs and value-added components.

Property 5: Impact Analysis

With the impact analysis, an MRIO can showcase the structural economic effects of a sudden impact on one of the model parameters, such as a sudden increase of final demand.

2.3. Strengths and Limitations

Models have their strengths and limitations, so they must be carefully chosen to suit the research question. The following papers extensively discuss the pros and cons of MRIO-tables [Ten Raa, 1994; Bess et al., 2011; Clouse et al., 2023]. The properties that are useful for this study are summarised below, for an extensive breakdown of the properties of the MRIO, I would like to refer you to these papers.

First, MRIOs effectively capture inter-industry relations both within and across regions, providing insights based on actual transaction values. Second, they are grounded in national accounting systems, relying on real-world economic data rather than assumptions or behavioural axioms [Clouse et al., 2023]. Third, MRIO tables encompass the full scope of the real economy—covering private and public sectors, households, exports, taxes, subsidies, and capital flows—making them well-suited for calculating macroeconomic indicators [Miller and Blair, 2009]. Fourth, MRIO's structure is transparent and methodologically straightforward. A MRIO model builds on a clear theoretical foundation with known and clear assumptions. If one agrees to these assumptions, a MRIO reflects a macro-equilibrium where total sectoral inputs match total outputs. Finally, MRIOs are particularly effective for conducting impact assessments, such as evaluating the direct and indirect effects of policy or economic shocks.

MRIO can be seen as a theory-based macro-economic equilibrium model incorporated with relations between all macro-economic actors, that suits itself for well-defined model computations. To achieve this, the MRIO relies on assumptions that introduce certain limitations.

First, the MRIO model assumes constant returns to scale, meaning that if the demand for a sector increases, all required inputs increase proportionally. As a result, the model cannot capture scale-related efficiencies or inefficiencies that may arise in real-world production processes. Second, input coefficients are fixed over the analysis period. This rules out adaptive behavior such as input substitution or technological change as described by Hicks' induced innovation or the Kaldor-Verdoorn effect. It essentially assumes that each sector produces a homogeneous good that requires an unchangeable recipe. Third, the demand-pull MRIO does not take into account supply constraints. The MRIO assumes that if we project a demand increase, all the inputs can easily follow this increase, without considering production constraints. Again, you see here a Keynesian concept, where the economy is always running below full capacity. In line with this limitation, the MRIO works, therefore, with fixed prices. If it is assumed that there is no supply constraint, no price changes will occur when resources become scarce. There is no invisible hand at play. Besides, there is no budget constraint when increasing final demand. When applying final demand shocks to the system, there is no consideration of so-called expenditure substitution effects. Think, for instance, of crowding-in and crowding-out effects, or interest-rate absorption effects when following New-Keynesian or New-classical economics. In summary, when final demand is increased, the model only captures internal multiplier effects, while overlooking potential external or systemic-wide effects.

2.4. Model Suitability

The objective of this research is to identify the EU-wide economic impacts of CCA investments and to evaluate how these activities contribute to value added. This requires a method that is both **granular**—in tracing interdependencies across countries and sectors—and **macro-economically comprehensive**, allowing for analysis of total output and value added. The MRIO model fits these requirements, as outlined earlier, but its assumptions and constraints must be clearly evaluated in the context of the research goals.

Among the key strengths of MRIO models is their ability to capture real-world inter-industry and inter-country relationships using transaction-based data grounded in national accounting (strengths 1 and 2). We aim to track how adaptation demand ripples across sectors and borders, and creates total CCA output and CCA induced value added. Since the MRIO framework is based on national accounting systems, our findings will reflect actual economic relations. Moreover, covering the full economy enables us to construct a detailed macroeconomic picture of CCA activities (strength 3). This will help by quantifying the macroeconomic metrics of adaptation investments. Additionally, MRIO's transparency (strength 4) and clear equilibrium assumptions make the model easy to interpret and reproduce. Especially for decision-makers and researchers, the implications of the model can be easily understood and reproduced. Lastly, impact assessments can trace system-wide impacts (strength 5). CCA spending often triggers complex ripple effects throughout the economy. MRIO models are equipped to quantify these effects by tracing how an initial change in final CCA demand propagates through the economy.

However, the limitations of the MRIO framework must be carefully considered with respect to CCA. A significant limitation lies in the assumption of technical coefficients that are fixed and the assumption of constant returns to scale. The model does not account for dynamic processes such as technological innovation or economies of scale. In our context, this limitation is mitigated by the study's focus on the current economic structure and short-run responses to CCA demand. We are not aiming to forecast future transitions or model endogenous innovation. Instead, we aim to understand how today's CCA-related spending flows through the existing economy. In doing so, we keep the framework static so we can retrieve descriptive results and avoid long-term prospective modelling.

Another concern is that MRIO does not incorporate supply constraints or price effects. This assumption is problematic when analysing large-scale interventions, capacity-limited sectors, or economies operating near full employment. However, CCA is still in its infancy, and remains a small part of the real economy. This lowers the chance of overburdening or constraining the sectors. Additionally, this study examines small, short-term increases in CCA demand rather than large, transformational shifts. For moderate demand shocks—such as incremental increases in public or private CCA spending—these assumptions may still yield informative insights. Nevertheless, since the model lacks budget constraints and substitution mechanisms, it is better suited for producing broad economic estimates than for evaluating detailed policy prioritisation.

Finally, MRIO results depend heavily on data quality and resolution. In our case, the MRIO tables contain sufficient resolution to capture sector-level dynamics, but we should be cautious not to over-interpret results since the sector resolution is still largely aggregated.

3 Research Conceptualisation

Chapter 3 provides the conceptualisation and methodology to address the main and sub-research questions. The primary focus of this chapter is to situate the approach within the broader academic context, highlighting why particular methods were selected, what assumptions are made, what alternatives were considered, and what trade-offs or limitations arise. The methodological components directly related to the research question follow standard procedures and are therefore presented concisely or included in the appendices. These standard procedures are primarily based on Miller and Blair's Input-Output Analysis [Miller and Blair, 2009].

The research conceptualisation follows the order of the research design; therefore, we start by briefly restating the research design.

3.1. Research Design

The research design consists of six components, with the first— **the Literature Review**—is already covered in Chapter 1. The remainder of the research is conceptualised as follows. First, within **MRIO Construction**, an adaptation-focused MRIO model is constructed through a series of 6 methodological steps. Once the MRIO model is built, it is used, within **MRIO Modelling**, to generate initial results. Each of the modelling techniques addresses one sub-research question and includes: MRIO output aggregation, GVC decomposition, and DVA-return. These results are then subjected to a **Global Sensitivity Analysis (GSA)**, which involves repeating the modelling process under varying assumptions to test the distribution of outcomes. Finally, the results, discussion, and policy advice are written in the component of **Findings & Policy Reflection**.

This model and the corresponding analyses are fully constructed within the PyCharm environment. Each of the steps discussed in detail below is organised into a dedicated PyCharm folder. Each folder contains two Python files: `Step_X_Functions.py`, which defines the relevant functions, and `Step_X_Execution.py`, which efficiently executes the step. Additionally, a Jupyter notebook named `Step_X_Detailed_Execution.ipynb` is included to explain each computation and provide background to the code.

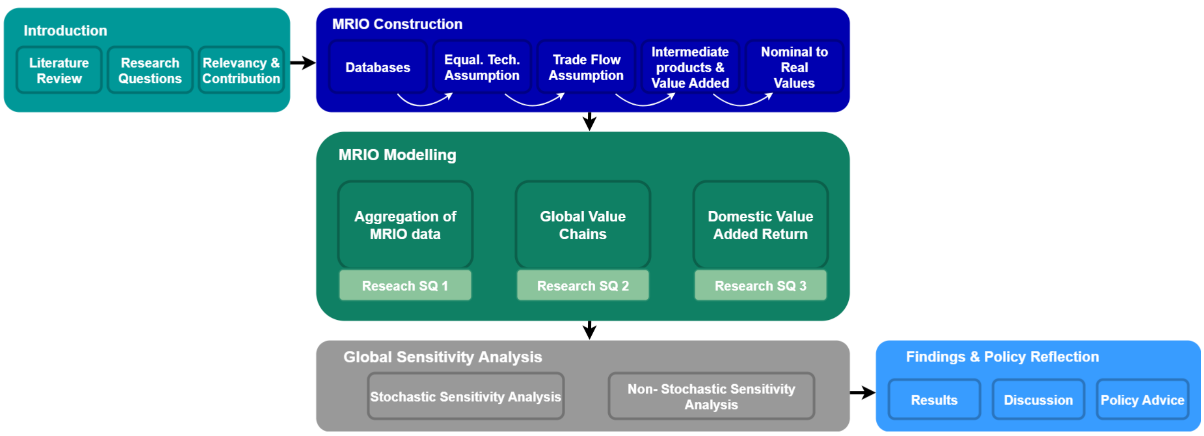

Figure 3.1.: Research Design *(Source: Own illustration)*

3.2. MRIO Construction

The research framework outlines six key steps involved in the construction of the MRIO. In this subsection, we will walk through the six steps for one particular MRIO. However, a MRIO is constructed for each of the five hazards and for each year from 2021 to 2023. We will construct an MRIO in current and constant prices; this leaves us with: 5 * 3 * 2 = 30 MRIOs.

3.2.1. Databases

Multiple databases are used to construct the MRIO model, see Table 3.1. The primary data come from the longitudinal kMatrix LTD database, which tracked climate change adaptation investment transactions across 27 EU countries and the UK, categorised by hazard type and economic sector [Howard et al., 2020]. 5 hazard types are identified: flooding, heatwave, drought, wildfire and the remaining are captured by other hazards. Sectors are classified by the NACE Rev. 2 level 1 economic sector division, which counts 19 sectors. The research uses a database spanning three calendar years, from 2021 to 2023. See Figure 3.2. The database includes two datasets. The first dataset contains national adaptation transactions across 27 EU countries and the UK, categorised by hazard type and economic sector. The second dataset includes sectoral transactions that detail intersectoral adaptation purchases on the European level for each type of hazard. This dataset provides information on which sectors supply adaptation solutions to other sectors, but it does not specify the country-to-country trade flows of these adaptation investments.

Databases	Unit	Source
National Adaptation Spending	Million Euro	[Howard et al., 2020]
Sectoral Adaptation Spending	Million Euro	[Howard et al., 2020]
MRIO Tables	Million Euro	[Eurostat, 2025]
MRIO Tables (Current Prices)	Million Euro	[Asian Development Bank, 2023]
MRIO Tables (Constant Prices)	Million Euro	[Asian Development Bank, 2023]
GDP Deflator	2018 starting value	[World Bank, 2025]

Table 3.1.: Overview of the used databases and their respective sources.

The tables of Eurostat, called *FIGARO Tables*, are used to extract trade relationships of EU countries. Alternatives such as Exciobase, Eora, WIOD and Asian Development Bank are considered [Stadler et al., 2021; Lenzen et al., 2012; Timmer et al., 2015; Asian Development Bank, 2023]. Eora and WIOD do not freely provide or have stopped providing recent MRIOs. Exciobase consists of large data structures and is not easy to process. Since Eurostat develops the FIGARO tables as part of the EU's official statistical system, they likely offer the most accurate and consistent representation of national accounts across EU member states. Moreover, it provides free access to the most up-to-date versions and is easy to process. Although there are minor methodological differences, studies found that the differences within Europe between these tables are minimal and arbitrary [Uchida and Oyamada, 2017]. The reason for this, according to the IMF, is that the above-mentioned institutions share and use each other's data sources and use similar methodologies [Borbon-Garcia et al., 2023]. The Asian Development Bank tables are used to fill data gaps in FIGARO and to extract the GDP deflators, as it is the only institution that publishes MRIO tables in both constant and current prices [Asian Development Bank, 2023]. As for countries that are not covered by the Asian Development Bank, World Bank deflators are used [World Bank, 2025].

3.2.2. Equal Technology Assumption

As outlined in *Databases*, the adaptation database consists of two datasets: one detailing sectoral final demand at the national level, and another showing intersectoral linkages at the European level. In this step, the two datasets will be merged, such that it not only identifies which sectors purchase

Countries	Economic Sector	Hazard
Austria	Agriculture, Forestry and Fishing	Wildfire
Belgium	Mining and Quarrying	Heatwave
Bulgaria	Manufacturing	Drought
Croatia	Electricity, Gas, Steam and Air Conditioning Supply	Flooding
Cyprus	Water Supply; Sewerage, Waste Management and Remediation Activities	Other
Czechia	Human Health and Social Work Activities	
Denmark	Construction	
Estonia	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	
Finland	Arts, Entertainment and Recreation	
France	Transportation and Storage	
Germany	Accommodation and Food Service Activities	
Greece	Information and Communication	
Hungary	Financial and Insurance Activities	
Ireland	Real Estate Activities	
Italy	Professional, Scientific and Technical Activities	
Latvia	Administrative and Support Service Activities	
Lithuania	Public administration and defence; compulsory social security	
Luxembourg	Other Service Activities	
Malta	Education	
Netherlands		
Poland		
Portugal		
Romania		
Slovakia		
Slovenia		
Spain		
United Kingdom		

Figure 3.2.: Parameters of the kMatrix LTD database

adaptation goods, but will also reveal which sectors supply them. The integration of these datasets relies on the Equal Technology Assumption (ETA). The ETA states that similar sectors across countries buy adaptation goods from a similar distribution of sectors when responding to the same climate hazard, see Figure 3.3. Note that the superscript implies the regions, whereas the first character is the supplying region and the second character is the receiving region, and the subscript represents the industries, where the first character is the supplying industry and the second is the buying industry. $F^{E,S}_{1,n}$ can be interpreted as final demand from supplying region E (i.e. Europe), towards region S from supplying sector 1 towards sector n.

		Final demand				
		Region 1		...	Region s	
		Fd1	Fdn		Fd1	Fdn
Europe	Industry 1	$F^{E,1}_{1,1}$	$F^{E,1}_{1,n}$		$F^{E,S}_{1,1}$	$F^{E,S}_{1,n}$
	...		**F**			
	Industry n	$F^{E,1}_{n,1}$				

Figure 3.3.: The final demand matrix after the Equal Technology Assumption *(Source: Own illustration)*

Columns represent the EU countries (i.e. Region 1) per individual sector (i.e. Fd1) buying final demand goods from a European-wide sector-wise distribution (i.e. Industry 1).

The fundamental question underlying the ETA is whether a sector across different countries buys adaptation goods from a similar set of sectors in response to the same hazard. While this assumption might seem simplified, there are several reasons to consider it a reasonable starting point, particularly in the context of adaptation goods in Europe.

First, the assumption is not applied uniformly across all contexts, but is differentiated by both climate hazard and sector [Howard et al., 2020]. Although the data are aggregated at the country level, the data distinguish between sectors and climate hazards. The question then becomes whether construction in Country A, fighting drought, buys adaptation goods from the same sectors as construction in Country B, also fighting drought. This still provides a limited but more meaningful level of granularity regarding adaptation goods. Second, adaptation literature showed that CCA supplying sectors are very concentrated, where some figures show water & waste management account for 50% of the total products[Climate Policy Initiative, 2020; Treville et al., 2022]. Besides, patent reviews show that most adaptation technologies rely on either scientific or engineering clusters [Hötte and Jee, 2022]. A first glance at the databases suggests that indeed three key supplying sectors—water & waste management, private services, and construction —consistently dominate the supply of adaptation-related products. This supports the idea that, at this stage, the sectors supplying adaptation goods across the different hazards may be more homogeneous than in more mature economic fields. Third, preliminary findings from the European State of the Climate report by the Copernicus Institute indicate that Northern, Southern, and Western Europe generally adopt similar types of adaptation measures, aligning with the European average [Copernicus Climate Change Service, 2024]. In contrast, Eastern Europe stands out by implementing fewer institutional measures. Fourth, given the high degree of economic agglomeration and interconnection in Europe, climate adaptation investments are likely to generate technological diffusion and knowledge spillovers, thereby converging on adaptation measures. Focusing on systematic adaptation is one of the cornerstones of the EU adaptation strategy, and a specific platform, Climate-Adapt, is implemented for this reason [European Commission, 2021]. Especially given that public or EU institutions still initiate most adaptation efforts, there is reason to believe that countries are converging in adaptation technologies [Climate Policy Initiative, 2023]. Finally, as most countries are still in the early stages of scaling up adaptation investments [Global Commission on Adaptation, 2019], the range of available technologies and suppliers remain relatively narrow, leading many countries to rely on similar types of inputs [Hötte and Jee, 2022].

That said, this assumption is not without limitations. One of the main challenges lies in the lack of country-level data on the sectoral composition used for adaptation products [Crawford and Church, 2019; Linnenluecke et al., 2013]. An alternative to the ETA would be to modify the EU-level sectoral mix for each individual country by establishing distinct national axioms. However, currently, it is infeasible to make valid assumptions about country-specific differences in adaptation purchasing patterns due to the lack of empirical evidence. For instance, adjusting for differences such as France relying more on knowledge-based solutions while Poland prioritises nature-based solutions would require country-level data on adaptation investments. Although efforts are made to classify adaptation instruments at the Key Type Measures level, only five countries adopted this classification system, making it insufficient to differentiate across countries [Leitner et al., 2021].

Methodology

The ETA is applying the EU-wide sectoral distribution on the individual national adaptation expenditures. The essential technical foundation is presented below. For the full mathematical derivation and an insightful practical example, refer to Appendix A

Let:

- S be the set of **sectors** ($s = 1, \ldots, 19$).
- H be the set of **hazards** ($h = 1, \ldots, 5$).
- $T^h_{S,s'}$ denote the **transactional value** from sector S towards sector s' for hazard h.

The EU-wide sectoral distribution can then be formulated as in equation 3.1.

$$T^h_S = \sum_{S \in s'} T^h_{S,s'} = \left[T^h_{S,s^1} + T^h_{S,s^2} + \cdots + T^h_{S,s^{19}} \right] \tag{3.1}$$

The transactional values are then normalised by dividing each individual supplying sector s' by the total purchase value of the sector S. Doing this, you obtain for each sector and hazard a EU-distribution set A^h_S, as shown in equation 3.2.

$$A^h_S = \sum_{S \in s'} A^h_{S,s'} = \left[A^h_{S,s^1} + A^h_{S,s^2} + \cdots + A^h_{S,s^{19}} \right] = 1 \tag{3.2}$$

Now we can load Part B of the database and import the national adaptation values for each sector. We multiply this national adaptation value by the list of nationwide distributions.

$$T^{C,h}_S * A^{C,h}_S = T^{C,h}_S * \sum_{S \in s'} A^{C,h}_{S,s'} = \sum_{S \in s'} T^{C,h}_{S,s'} = [\ T^{C,h}_{S,s^1} + T^{C,h}_{S,s^2} + ... + T^{C,h}_{S,s^{19}}] \tag{3.3}$$

Equation 3.3 shows that now for each sector S in each country C, it is known how much they purchase from the other sectors s' for each hazard h.

3.2.3. Trade Flow Assumption

In the previous step, purchasing sectors were disaggregated to the national level. In the current step, a similar disaggregation is applied to the supplying sectors. This is achieved using the Trade Flow Assumption (TFA), which implies that the distribution of adaptation goods across countries mirrors the trade flow patterns of the broader economy. Adopting this assumption enables a clear picture of the geographic origin of final adaptation products. See Figure 3.4

Although exceptions exist, adaptation investments flow through the structure of the general economy. There is no certain isolated adaptation economy, with specific adaptation industries and adaptation supply chains. Adaptation goods are, therefore, an incremental extension of the already existing supply chains of the general economy [Lacambra et al., 2020; Enfield, 2020]. So, instead of asking the question: What does the adaptation supply chain look like, the question becomes: Which existing supply chains are sourced for adaptation purposes? Since we have this information (i.e. we know from which sectors adaptation goods are bought from), we can roughly assume that within the correct collection of supply chains, adaptation products follow the general production. Second, countries tend to rely on established trade relationships [Proudman and Redding, 1997; Gereffi and Lee, 2012]. This is, among other things, based on bilateral trade agreements, historical connections, trust, and political

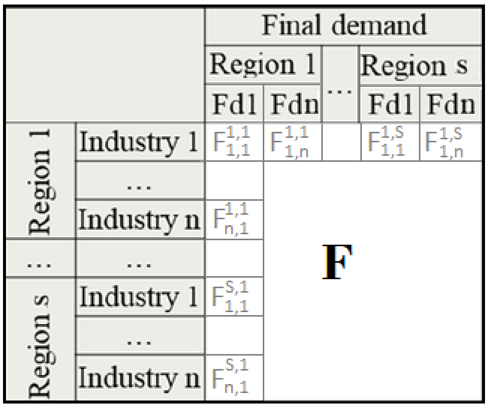

Figure 3.4.: The final demand matrix after the Trade Flow Assumption. *(Source: Own illustration)*

Columns represent the EU countries (i.e. Region 1) per individual sector (i.e. Fd1) buying final demand goods from a national level (i.e. Row Region 1) and sector-wise distribution (i.e. Row Industry 1).

values [Eichengreen and Irwin, 1996; Eicher and Henn, 2011; Augier et al., 2005]. Besides, it appears that companies tend to prioritise sourcing within their existing network—often referred to as supply chain stickiness—rather than establishing new trade linkages[Martin et al., 2023]. A third and last argument, grounded in Ricardian trade theory, highlights the role of comparative advantages, resulting in a world more and more **vertically specialised** [Hummels et al., 2001]. Vertical specialisation implies that countries specialise in certain production sectors because of comparative advantages [Arndt and Kierzkowski, 2001].

> *Let us illustrate these three arguments in one example.* The forestry industry in Lithuania is able to export wood cheaply; this comparative advantage does not change across the general market or adaptation market. This industry is now having an additional wood demand for adaptation purposes, which results in increasing their own inputs, but not changing their own supply chains.

There are, however, three uncertainties. First, coming back to the Ricardian trade theory, adaptation can change the vertical specialization perspectives. Whereas the Netherlands might not be a construction export country par excellence, it possibly is within the specialised sector of flood constructions. It is therefore important to be alert to hazard-specific specialisations of countries. A second uncertainty is the locally bounded nature of adaptation products. Adaptation goods are highly location-specific and must be tailored to local conditions and needs [Global Commission on Adaptation, 2019; Cortekar et al., 2016; Surminski et al., 2018]. This can increase the domestic supply ratio. Lastly, in the academic literature, there has been more attention towards maladaptation efforts, or mitigation-increasing adaptation efforts [United Nations Environment Programme, 2022; Magnan et al., 2016]. It can be reasoned that adaptation, which is in close relation to the mitigation field, tries to limit its mitigation activities. This would mean that adaptation products would be sourced more domestically than internationally.

Alternative methods (i.e. Gravitation Economic Model, CGE or Entropy maximisation) for estimating trade relations within MRIOs do not come close to the sector-country granularity of MRIO relationships [Mi et al., 2018; Roy and Thill, 2004]. Besides, the three above-mentioned uncertainties will still not be mitigated.

Methodology

The trade flow coefficients of EU27 are estimated through the FIGARO MRIO tables and regarding the UK through the tables of the Asian Development Bank, because of unreliable UK public values in the FIGARO-tables. France's national trade flow coefficients appear disproportionate to its imports across various MRIO tables and Supply-Use Tables. While this doesn't impact aggregate results, it could skew national metrics like DVA-return or spillover effects. France has therefore been excluded. In addition, Finland has been excluded since no reliable GVC could be constructed. The tables from 2021 to 2022 are used, since a MRIO table for 2023 is not yet available, we will rely on the 2022 data. Trade flow coefficients tend to remain stable over short periods, particularly within a one-year timeframe [Clouse et al., 2023]. FIGARO specifies final demand in 5 categories, where we will use *Gross Fixed Capital Formation* (i.e. P51G) and *Final consumption expenditure of general government* (i.e. P3_S13). The final demand will be (28 countries * 19 industries =) 532 columns and (46 countries * 19 industries =) 874 rows. This is because purchasing countries cover only EU27 and the UK, while supplying countries follow the FIGARO set of 46 countries, see Appendix C for the full FIGARO breakdown.

The kMatrix LTD database classifies economic activity into 19 sectors, whereas the FIGARO dataset includes a more detailed breakdown of 56 sectors. To align the two, the aggregation of FIGARO sectors is necessary. FIGARO sectors are labelled using NACE Rev. 2 codes (e.g., A01, A02, A03), allowing for straightforward aggregation based on their initial letter to match a 21-sector classification. The remaining two sectors, T (Activities of households as employers) and U (Activities of extraterritorial organisations), contribute negligibly to the overall economy. Section T reflects activities that are considered a form of final consumption rather than productive input in the economy. This was specifically verified for Belgium, where the presence of numerous EU institutions might suggest a larger share in sector U. However, even in this case, the contribution remains minimal. Therefore, these sectors are excluded. This decision does not compromise the internal consistency of our results, as the analysis is based on relative distributions. We examine how adaptation-related spending is distributed across sectors, not the total volume. The exclusion of these sectors has been validated, refer to: `Step_3_Detailed_Execution.ipynb`.

The essential steps of the technical derivation are presented below; for the full mathematical derivation and an insightful practical example, refer to Appendix B.

Let:

- C be the set of **countries** ($C = 1, \ldots, 46$)
- S be the set of **sectors** ($S = 1, \ldots, 19$)
- $T^S_{C,c'}$ denote the **transactional value** from country C towards country c' for particular sector S

$$T^S_C = \sum_{C \in c'} T^S_{C,c'} = \left[T^S_{C,c^1} + T^S_{C,c^2} + \cdots + T^S_{C,c^{46}} \right] \tag{3.4}$$

The total transactional value of sector S in country C combines domestic and foreign purchases (Eq. 3.4). Normalising each value by this total yields trade flow coefficients per industry (Eq. 3.5).

$$A^S_C = \sum_{C \in c'} A^S_{C,c'} = \left[A^S_{C,c^1} + A^S_{C,c^2} + \cdots + A^S_{C,c^{46}} \right] = 1 \tag{3.5}$$

This trade flow coefficient list shows how much of the industry share of a particular country is coming from domestic sources and/or foreign countries. If we multiply this list by the absolute transactional value of the industry, we will receive trade flow transactional values. See equation 3.6

$$T^{S,s'}_C * A^S_C = T^{S,s'}_C * \sum_{C \in c'} A^S_{C,c'} = \sum_{C \in c'} T^{S,s'}_{C,c'} = [\ T^{S,s^1}_{C,c^1} + T^{S,s^1}_{C,c^2} + ... + T^{S,s^1}_{C,c^{46}}] \tag{3.6}$$

Where:

- $T^{S,s'}_C$ implies the transaction T from sector S in country C towards sector s'
- A^S_C The Trade Flow Coefficient list from a sector S in country C.
- $T^{S,s'}_{C,c'}$ implies the purchase values from sector S in country C towards sector s' in country c'.
- $\sum_{C \in C'} T^{S,s'}_{C,c'}$ implies the full list of purchases of sector S in country C towards sector s' across all countries.

3.2.4. Intermediate Products and Value Added

At this stage, we have constructed the final demand matrix of the MRIO. What remains is the incorporation of backward linkages, which are denoted in the *Z-matrix*. The adaptation suppliers also rely on inputs, and to fully trace the production of adaptation goods, we need to identify the origin of these intermediate inputs. This information can be adopted from the *FIGARO* intermediate use matrix, which provides a detailed mapping of input flows between industries. We are not using the absolute numbers of the general economy, but the technical coefficients and value-added coefficients for each industry and country.

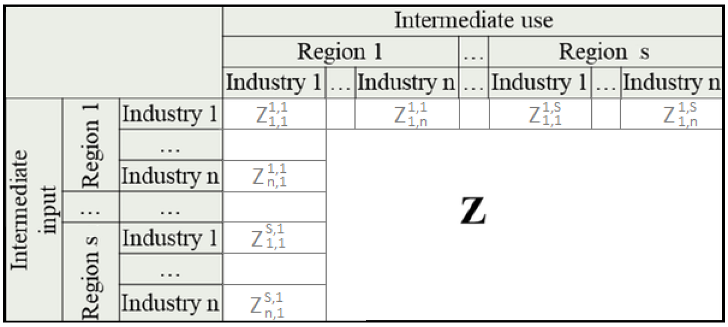

Figure 3.5.: Intermediate Input Matrix. *(Source: Own illustration)*
Columns represent the EU and non-EU countries (i.e., Region 1) per individual sector (i.e., Industry 1) buying intermediate goods from a national level (i.e., Row Region 1) and sector-wise distribution (i.e., Row Industry 1).

The same can be done regarding the Value Added within these intermediate sectors.

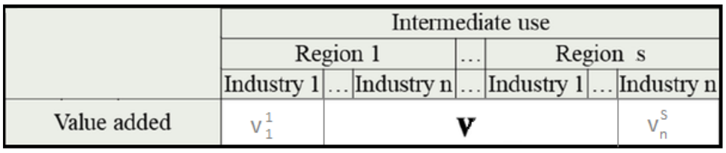

Figure 3.6.: Value Added Matrix. *(Source: Own illustration)*
Columns represent the EU countries (i.e., Region 1) per individual sector (i.e., Industry 1) generating Value Added.

Unlike final adaptation products, which are explicitly linked to climate adaptation spending, intermediate products are embedded within general economic transactions and do not carry an explicit adaptation label. These intermediate trade flows can be reliably inferred from existing MRIO tables.

> *Let us illustrate this again with the forestry industry in Lithuania*. For their adaptation requests, they need an additional truck. A truck factory in Germany is building this truck, thus increasing its inputs. Whether the truck is built for adaptation purposes or not, it would, with all probability, not affect their input matrix, since the truck is built the same way. In fact, it is often not even known by the truck producer whether their truck is used for adaptation purposes or not.

Methodology

This step retrieves coefficients of the regular *Z-matrix* and *va-vector* of the FIGARO Tables and applies this to the adaptation of the MRIO Table. The aggregation method to align the NACE Rev. 2 codes with the kMatrix LTD is similar to the one used with the final demand matrix. With respect to the intermediate matrix, we have accurate importing and exporting data in the 46 regions of the world. This means the intermediate matrix has (49 * 19 =) 874 columns and (49 * 19 =) 874 rows. The mathematical computations follow the standard procedure of Miller and Blair [Miller and Blair, 2009]. In here, the steps are written concisely; for the full mathematical elaboration, refer to Appendix D.

The column of the inter-industry transactions matrix Z represents all the inputs required by a particular sector to produce its total output. By dividing each element in a column by the total output of that sector, we obtain the *technical coefficients*, and they form the *technical coefficient matrix*, also called the **A**-matrix. The technical coefficient matrix is defined in full matrix notation in Equation 3.7 and written concisely in Equation 3.8. In here, we continue with the second approach, but keep in mind these values represent matrices and vectors; again, refer to Appendix D for the full matrix notation.

$$\begin{bmatrix} a_{1,1}^{1,1} & \cdots & a_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ a_{1,j}^{1,s} & \cdots & a_{i,j}^{r,s} \end{bmatrix} = \begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ z_{1,j}^{1,s} & \cdots & z_{i,j}^{r,s} \end{bmatrix} * \begin{bmatrix} \frac{1}{x_1} & & \\ & \ddots & \\ & & \frac{1}{x_n} \end{bmatrix} \tag{3.7}$$

$$\mathbf{A} = \mathbf{Z}\,\hat{\mathbf{x}}^{-1} \tag{3.8}$$

This technical coefficient matrix can also be constructed for the value added vector, you would then include the share of primary inputs needed for the total output. See equation 3.9.

$$\begin{bmatrix} v_1^1 & \ldots & v_i^r \end{bmatrix} = \begin{bmatrix} va_1^1 & \ldots & va_i^r \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{x_1^1} & \cdots & \frac{1}{x_1^r} \end{bmatrix} \tag{3.9}$$

At this point, we have constructed the technical coefficient matrix, denoted by **A**. The next step is to construct the *Leontief inverse*. The Leontief inverse quantifies the total *direct and indirect* output requirements throughout the economy resulting from a change in final demand. The *direct effect* refers to the immediate output generated by a final demand transaction, *the indirect effect* represents the backward linkages. The fundamental input-output relationship expressed in equation 3.8 can be reformulated as 3.10. From another input-output relationship, we know that **Zi** can be expressed by equation 2.2. We will rewrite this equation such that **Zi** is isolated, see equation 3.11

$$\mathbf{Zi} = \mathbf{Ax} \tag{3.10}$$

$$\mathbf{Zi} = \mathbf{x} - \mathbf{Fi} \tag{3.11}$$

Using the 3.10 and 3.11 identities , we can reformulate the system in mathematical terms as equation 3.12.

$$\mathbf{x} = \mathbf{Ax} + \mathbf{Fi} \tag{3.12}$$

Finally, we have to rewrite this function so that x gets isolated. This is done through equation 3.13.

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Fi} = \mathbf{LFi} \tag{3.13}$$

So, formally, the Leontief inverse is given by:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \tag{3.14}$$

The Leontief inverse matrix is compiled from the identity matrix **I** and the technical coefficient matrix **A**, as shown in equation (3.14). The **A**-matrix itself is constructed from the **Z**-matrix and the total output vector **x**, both of which are extracted from the FIGARO Input-Output tables. As a result, the Leontief inverse matrix we compute at this stage closely mirrors that of the general economy. This makes sense, since we introduced the TFA that an adaptation-related product follows the same trade flow pattern as a general product within the same sector. The technical coefficients and Leontief inverses are based on the FIGARO tables, and are thus not yet modified to the adaptation purchases. If we subsequently multiply the Leontief inverse Matrix **L** with the total final adaptation demand vector, we would, following the logic above, obtain its total adaptation output. We do this through equation 3.13.

We have extracted the total adaptation output **x**−vector at the sector and country level and previously retrieved the final adaptation demand **F**−matrix. The final step is to transform the intermediate matrix **Z**, which is currently in Leontief format, into actual adaptation-related purchases. This is done by multiplying the technical coefficient matrix **A** by the total adaptation output vector **x**. This operation scales the input shares to match the actual adaptation-related production levels in each sector. This is done through the reverse logic of equation 3.7 and 3.9, see equations 3.15 and 3.16.

$$\begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ z_{1,j}^{1,s} & \cdots & z_{i,j}^{r,s} \end{bmatrix} = \begin{bmatrix} a_{1,1}^{1,1} & \cdots & a_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ a_{1,j}^{1,s} & \cdots & a_{i,j}^{r,s} \end{bmatrix} * \begin{bmatrix} x_1^1 \\ \vdots \\ x_j^s \end{bmatrix} \tag{3.15}$$

$$\begin{bmatrix} va_1^1 & \ldots & va_i^r \end{bmatrix} = \begin{bmatrix} v_1^1 & \ldots & v_i^r \end{bmatrix} \cdot \begin{bmatrix} x_1^1 & \ldots & x_1^r \end{bmatrix} \tag{3.16}$$

3.2.5. Nominal to Real Terms

Within this study, a double deflation method is used for deflating the MRIOs. The double deflation method states that if we deflate a sector's inputs using the unique input deflators, and we deflate the output according to the sector's output deflator, the residual yields the deflated value added [Los et al., 2014]. This method would bring the most accurate deflation numbers per industry and country, and is the preferred method of the European Commission, OECD and WorldBank [European Commission et al., 2009]. First of all, double deflation adds more detail by adjusting output and input prices separately. Next to this, in contrast with the single deflation method, where solely the total output deflator is used on the value added, the double deflation method retains the MRIO balance. Recalling notion 1 of the MRIO, the balancing accounting principle, where the input equals the output. Concerning the single deflation method, the balancing feature of the MRIO is not preserved. Next to that, notion 2 of the MRIO is violated as well by the single deflation method. GDP can be computed in three ways. If we only deflate the output of the industries, the GDP output computation will deviate from the GDP income and GDP expenditure computations [Oulton et al., 2018].

Aside from translating the MRIO from current to constant prices, there is an additional translation that translates purchasers to basic prices. Using basic prices ensures that only the actual transaction, flowing from sector i towards sector j, feeds back into the intermediate use matrix. Net taxes and margins instead go to the government or service providers and account for the part that makes Gross Value Added to GDP. Basic and purchaser prices are different measures that, in the end, change the allocation of value added across sectors and countries. We proceed with purchaser prices, as they are the only data consistently available across countries and years within our MRIO framework. Additionally, adapting the full dataset to basic prices would require detailed and often unavailable tax and margin breakdowns by year, sector and country.

Methodology

The double deflation method argues: if we deflate **x** and deflate **Z**, we can retrieve the deflated **va**, or real value added. In MRIO technical terms, this means: deflate each row in the **Z**−matrix with its unique deflator. This is called *uniform row evaluation*. If we then subtract the sum of the columns of the deflated **Z**−matrix from the deflated **x**−vector, we get the deflated **va**−vector.

To perform the *uniform row valuation*, we need sectoral- and country-level deflators, which are (19 * 46 =) 874 unique deflators. These are obtained from the Asian Development Bank databases, since they have MRIOs in current and constant prices. The deflator for sector i in country c at year t is computed as:

$$d_{i,c,t} = \frac{x_{i,c,t}^{\text{curr}}}{x_{i,c,t}^{\text{const}}} \tag{3.17}$$

where $x_{i,c,t}^{\text{curr}}$ is the total output at current prices, and $x_{i,c,t}^{\text{const}}$ is the total output at constant prices. To ensure comparability across time, all deflators are rebased to the beginning of the adaptation dataset, which is 2018. This is done through:

$$d_{i,c,t} = \frac{d_{i,c,t}}{d_{i,c,2018}} \tag{3.18}$$

where $d_{i,c,t}$ is the deflator for sector i in country c at year t.

Argentina, South Africa and Saudi-Arabia are not covered by the Asian Development Bank. We therefore extract deflators from the World Bank national accounts and similarly rebase them to 2018. The final step is to subtract the deflated $\mathbf{Z}$ from the deflated $\mathbf{x}$, we then have the deflated $\mathbf{va}$.

3.3. MRIO Modelling

The MRIO model is now constructed. The next step is to infer insights from the model. We begin by identifying relevant structural *Demand & Output*, followed by decomposing the *GVC*, finally extracting the *DVA-returns* of private and public investments.

3.3.1. CCA Output

The analysis of Demand & Output relations serves as a starting point, as it provides an initial overview of the key sectors and countries involved in adaptation-related production. Analysing the structural output involves identifying which sectors and countries are the primary purchasers and suppliers of adaptation goods and services, and how their contributions differ across climate hazard types.

Methodologically, this step serves as the baseline from which further analyses—such as GVC tracing and DVA-returns—can be built. The total adaptation output does not require further methodological computations; it is an act of aggregation. Demand and output computations have been performed by aggregating final demand, intermediate demand or gross output concerning countries, hazards, supplying sectors, purchasing sectors and type of product (final good vs intermediate good), see Table 3.2.

Disaggregation	**Aggregation**	**Formula**
Country (c) and hazard (h)	Supplying sector (s), purchasing sector (p) and product type (b),	$\sum_s \sum_p \sum_b x_{c,h,s,p,b}$
Hazard (h), supplying sector (s) and product type (b)	Country (c) and purchasing sector (p)	$\sum_c \sum_p x_{c,h,s,p,b}$
Supplying sector (s), purchasing sector (p), product type (b)	Country (c) and hazard (h)	$\sum_c \sum_h x_{c,h,s,p,b}$

Table 3.2.: Selected levels of aggregation with respect to final demand and gross output

In addition to the above-mentioned aggregations, an output-expenditure ratio is computed. This ratio shows the national output, including domestic output and export, divided by the national CCA expenditure and can be formulated as equation 3.19:

$$\text{Output-Expenditure Ratio}_i = \frac{\sum_j x_j^i}{\sum_j \sum_r \sum_s f_{js}^{i,r}} \tag{3.19}$$

Where:

- x_j^i = gross output of sector j in country i (including domestic production and exports)
- $f_{jk}^{i,s}$ = final demand in sector j of country i for products from sector s in country r

3.3.2. Global Value Chains

The second modelling technique is used to examine the value added generated by these investments. This is done by tracing value added along GVC. Unlike traditional trade statistics, GVC analysis captures a full range of value added generation across sectors and borders. It has the unique ability to compute highly granular value-added metrics, particularly with regard to exports. For instance, GVC analysis accounts for reflection (DVA that is exported and subsequently re-imported), and double counting (DVA that is exported to one country and then re-exported to another), and computes net value added streams.

GVC analysis is a relatively recent development. There are, however, already different decompositions possible to extract the GVC. The framework of Koopman et al. (2014) was the first to decompose the value added along the supply chain in DVA, FVA, reflection (DVA that is exported and subsequently re-imported), and double counting (DVA that is exported to one country and then re-exported to another) [Koopman et al., 2014]. However, their approach has several limitations. Most notably, it does not account for bilateral or sectoral trade relationships, and it applies inconsistent perspectives—using a country-level approach for DVA and a global perspective for FVA [Feás, 2023]. Subsequent efforts attempted to address these shortcomings. Wang et al. (2013) expanded the decomposition approach to include bilateral exports [Wang et al., 2013]. Nagengast and Stehrer (2016) introduced the important distinction between source-based (where value added is generated) and sink-based (where value added is ultimately absorbed) approaches, but did not apply this distinction systematically in their calculations [Nagengast and Stehrer, 2016]. Miroudot and Ye (2021) build on this but argue against further disaggregation by final demand [Miroudot and Ye, 2021]. The most comprehensive and consistent framework is therefore provided by Borin and Mancini (2023) [Borin and Mancini, 2023]. They develop a general method that constructs a full decomposition of both DVA and FVA, applicable at the aggregate, bilateral, and sectoral levels [Feás, 2023].

All these methods only focus on the value added with respect to exports and imports. Within these frameworks, there is no computation of DVA induced by domestic final demand. Although the world is more vertically globalised, some supply chains are considered to be domestic-oriented, for instance, the supply chains of the public sector [Becker et al., 2019]. For these DVA patterns, the Trade in Value Added (TiVA) methods of the OECD are applied or are manually computed [OECD, 2019].

Methodology

The GVC decomposition is performed primarily on the `exvatools` package in R and manual matrix operations in Python for greater flexibility over custom aggregations [Feas, 2024]. The decomposition is based on the method of Borin and Mancini [Borin and Mancini, 2023]. This method is a bilateral decomposition of gross exports, providing insight into the origin and destination of value added, see equation 3.20. The metrics of equation 3.20 were selected to obtain the exported DVA and FVA of intermediate - and final adaptation products of EU countries. For the full derivation, refer to Appendix F. For gross exports from country i towards country j (X_{ij}), the decomposition is defined as:

$$X_{ij} = \text{DVA}_j^i + \text{FVA}_j^i + \text{RDV}_j^i \tag{3.20}$$

Where:

- DVA_j^i: Domestic Value Added absorbed in the importing country.
- FVA_j^i: Foreign Value Added embedded in the exports of i.
- RDV_j^i: Returned Domestic Value Added, i.e., value created in i, exported, and re-imported.

In contrast to the method of Borin and Mancini, the OECD's TiVA method is able to capture value added in domestic final demand [OECD, 2019]. TiVA OECD's indicators are computed through `exvatools`, the manual decompositions are computed in Python, both relying on the logic of formula 3.21. The formula is shown in the most disaggregated format.

$$\mathbf{V}_{j,s}^{i,r} = \hat{\mathbf{v}}_j^i \cdot \left[(\mathbf{I} - \mathbf{A})^{-1} \right]_{j,s}^{i,r} \cdot F_{j,s}^{i,r} \tag{3.21}$$

Where:

- $\hat{\mathbf{v}}$: Diagonal matrix of value-added coefficients. Each element v_j^i on the diagonal represents the share of value added in total output for sector j in country i.
- The global Leontief $\left[(\mathbf{I} - \mathbf{A})^{-1} \right]_{j,s}^{i,r}$ captures the (direct and indirect) total output of country i in sector j induced by final demand of country r in sector s.
- $\mathbf{F}$: Final demand matrix of dimension $NS \times NS$, where $F_{j,s}^{i,r}$ denotes final demand of country i, sector j towards country r with sector s.
- $\mathbf{V}_{j,s}^{i,r}$: Value added generated in sector j of country i that is embodied in the final demand for sector s in country r.

Metric	**Method**	**Description**
DVA	Borin-Mancini	Domestic value added embedded in exports
DVA_INT	Borin-Mancini	Domestic value added embedded in intermediate exports
DVA_FIN	Borin-Mancini	Domestic value added embedded in final exports
FVA	Borin-Mancini	Foreign value added embedded in exports
FVA_Share	Borin-Mancini	Share of foreign value added embedded in total value added in exports. *For adaptation - and general economy purposes.*
DXD_DVA	OECD TiVA & Manual	Domestic value added absorbed in domestic final demand
FFD_DVA	OECD TiVA & Manual	Domestic value added absorbed in foreign final demand
FFD_DVA_Share	OECD TiVA & Manual	Domestic value added absorbed in foreign final demand as share of total value added. *For adaptation - and general economy purposes.*
FFD_DVA_ind_Share	OECD TiVA & Manual	Share of indirect DVA of total DVA in foreign final demand: via other domestic sectors. *For adaptation - and general economy purposes.*
Import_Int_Share	OECD TiVA & Manual	Share of intermediate imports in total imports. *For adaptation - and general economy purposes.*

Table 3.3.: Summary of value-added trade metrics computed

Besides these TiVA metrics, a ratio is computed to compare the value added induced by CCA investments with the value added generated in the national general economy, see equation 3.22:

$$\text{VA Ratio}_i = \frac{\sum_j VA - CCA_j^i}{\sum_j VA - general_j^i} \tag{3.22}$$

In addition to the full European decomposition of the CCA GVC, a **case study** is performed to showcase localised GVC effects induced by a joint EU-Slovenian adaptation initiative, **LIFE4ADAPT** [European Commission, 2025]. In this context, short-run impact analysis is used to provide localised insights, reflecting only the consequences of this specific increase in final demand. LIFE4ADAPT is co-financed by the European Union and Slovenia, with a contribution from the EU of €14,177,980, whereas the total fund includes: €26,580,389 [European Commission, 2025]. In this study, only the EU-funded part is used. The LIFE4ADAPT fund in Slovenia is distributed across Slovenian sectors in the final demand matrix, following the distribution pattern of 2023. Afterwards, the trade flow coefficients for each individual Slovenian sector are applied to the sectoral individual budget. This case study does not involve a GSA.

Let:

- $F_{j,s}^{(\mathrm{SI}),r}$ denote the final demand in sector j of Slovenia ($i = \mathrm{SI}$) directed to sector s in country r (non-zero only for $i = \mathrm{SI}$),
- $L_{j,s}^{i,r}$ denote the element of the Leontief inverse indicating the output in sector j of country i generated by one unit of final demand in sector s of country r,
- x_j^i denote the total output in sector j of country i.

Then the output in sector j of country i is:

$$x_j^i = \sum_r \sum_s L_{j,s}^{i,\mathrm{SI}} \cdot F_s^{(\mathrm{SI}),r} \tag{3.23}$$

The domestic value added in sector j of country i is:

$$\mathrm{DVA}_j^i = v_j^i \cdot x_j^i = v_j^i \cdot \left(\sum_r \sum_s L_{j,s}^{i,\mathrm{SI}} \cdot F_s^{(\mathrm{SI}),r} \right) \tag{3.24}$$

where:

- v_j^i is the value-added coefficient for sector j in country i,
- DVA_j^i is the domestic value added in sector j of country i.

Lastly, the value-added content is aggregated per country, such that we retrieve the value added per country induced solely by the final demand of Slovenia. The countries that are involved in the matrix are the 46 countries used earlier, which are adopted from the FIGARO tables. Refer to Appendix C to inspect the related countries.

3.3.3. Domestic Value Added Return

The final method for extracting insightful metrics from the MRIO framework involves estimating the multiplying effects of an initial adaptation investment. This is normally done through MRIO multipliers. These multipliers aim to approximate the traditional Keynesian multiplier, but calculated in a multisectoral model [Bess et al., 2011]. Specifically, MRIO multipliers rely on linear income–consumption assumptions [Coughlin and Mandelbaum, 1991; Hall, 2009], absence of income- and consumption disaggregation and a time-delay component [Emonts-Holley et al., 2015; Grady and Muller, 1988]. Recent studies have begun integrating behavioural assumptions into MRIO frameworks; however, linear income-consumption assumptions are still the common practice. [Kratena and Streicher, 2017; Chen et al., 2010; Oosterhaven et al., 2019].

In this study, we focus on the generation of value added per country. To that end, we concentrate on the internal - and external value-added multipliers, as defined by Miller and Blair [Miller and Blair, 2009]. Rather than using internal - or external value-added multipliers, we adopt a more refined approach by analysing the **Value Added Return of Final Demand**. This metric captures the amount of value-added that is induced per unit of final demand, see Box 1. We derive this metric, in part, from OECD TiVA (Trade in Value Added) indicators, where this metric is defined as: value added content in final demand [OECD, 2023]. However, it is crucial to note that while TiVA provides the absolute value added, our measure represents its share of the total initial investment, not the absolute amount.

We will use the value added return of final demand, solely to infer the domestic value added generation by final demand; therefore, from now on, we will call this metric: **Domestic Value Added Return of Final Demand** or shortened **DVA-return of Final Demand** or just **DVA-return**. Compared to the internal value-added multiplier, the DVA-return captures the full chain of upstream economic activity stimulated by the actual adaptation investment. It provides a realistic representation of inter-sectoral linkages and reflects how the final demand influences the value added that is generated in the economy. Moreover, it relies on observed expenditure patterns and avoids assuming arbitrary expenditures.

Methodology

The DVA-return of final demand quantifies the DVA generated by a particular increase of final demand, and can be computed through equation 3.25

$$\mathbf{DVA}_{\text{return}} = \frac{\text{Induced Domestic Value Added}}{\text{Investment Expenditure}} = \frac{\hat{\mathbf{v}}^{(i)}\,\mathbf{L}\,\mathbf{f}^{(i,h)}}{\sum_{j=1}^{n} f_j^{(i,h)}} \tag{3.25}$$

If domestic value added is to be disaggregated by individual hazard, sector, country, or across all three dimensions, a fully disaggregated version of the equation is required.

Let:

- $\mathbf{L} \in \mathbb{R}^{n \times n}$ be the global Leontief inverse;
- $\hat{\mathbf{v}}^{(i)} \in \mathbb{R}^{1 \times n}$ be the value added coefficients for country i (zero elsewhere);
- $f_j^{(i,h)}$ be the adaptation-related final demand in sector j for country i under hazard h.

Summing across all sectors j, the total domestic value added generated in country c under hazard h is:

$$DVA^{(c,h)} = \sum_{j=1}^{n} DVA_j^{(i,h)} = \sum_{j=1}^{n} \left(\mathbf{v}^{(i)}\mathbf{L}\right)_j \, f_j^{(i,h)} \tag{3.26}$$

To assess efficiency per euro spent, we compute the DVA-return:

$$\mathbf{DVA}_{\text{return}}^{(i,h)} = \frac{DVA^{(i,h)}}{\sum_{j=1}^{n} f_j^{(i,h)}} \tag{3.27}$$

This fully disaggregated DVA-return reflects the domestic value added return per unit of final adaptation demand. Higher values of $\mathbf{DVA}_{\text{return}}^{(i,h)}$ indicate stronger short-term domestic economic benefits. As such, they can be used as an economic criterion for MCA for CCA decision making.

Box 1: VA Multiplier (VAM) vs Value Added Return of Final Demand

VA Multiplier: measures how much value added is generated in the economy by a certain increase.

Example: Agriculture receives an increase of 1 million euros in final demand, which leads to:

- 0.3 million euros of value added in agriculture
- 0.1 million euros of value added in transport

Then the Value Added Multiplier is:

$$\text{VA Multiplier} = (0.3 + 0.1)/1 = 0.4$$

Keep in mind that this 1 million increase in agriculture is arbitrary and not linked to actual final demand.

Value Added Return of Final Demand: captures the amount of value added that is induced per unit of final demand, weighted by the sectoral distribution of that demand.

Example: Suppose construction invests 1 million euros in adaptation goods, distributed as follows:

- 0.2 million to agriculture (VAM = 0.4)
- 0.4 million to manufacturing (VAM = 0.5)
- 0.4 million to professional services (VAM = 0.6)

Then the value added created by this investment is:

$$\text{Value Added Return} = (0.2 \cdot 0.4) + (0.4 \cdot 0.5) + (0.4 \cdot 0.6) = 0.52$$

Whereas the VAM uses an arbitrary demand shock, the Value Added Return reflects actual final demand composition. This DVA-return can be interpreted as a weighted average value-added multiplier.

3.4. Global Sensitivity Analysis

Modelling comes with uncertainty. Uncertainty can slip through the data or within the assumptions used in the model. A substantial part of the uncertainty comes through the ETA and TFA assumptions.

Early approaches to uncertainty analysis in Input-Output (IO) modelling primarily focused on deterministic sensitivity tests, running pre-defined simulations, and local sensitivity methods, i.e. varying a selection of parameters instead of varying an entire IO-table [Quandt, 1958, 1959]. The uncertainty addressed concerned the uncertainty in the Leontief inverse resulting from variability in the input–output coefficients. Although the techniques are sound and the results impactful, the findings are less robust due to an incomplete exploration of the uncertainty space [Bullard and Sebald, 1977]. In the case of the study of Bullard and Sebald, only the worst-case combinations were studied. In the background, there was an academic discussion going on whether the errors of the IO model were normally distributed, not correlated and stochastic. [Hanseman and Gustafson, 1981; Lenzen, 2001]. Bullard and Sebald, convinced that the uncertainty was stochastic, advanced their methods and introduced stochastic analysis, no pre-defined ranges, into IO-modelling [Bullard and Sebald, 1988]. Aligned with the thoughts of Bullard and Sebald, Weber and Lenzen applied it in MRIO modelling [Weber and Matthews, 2007; Lenzen et al., 2004]. Weber, correctly stated, that in comparison with IO-models, MRIOs even include more uncertainties: treatment of the Rest of the World, constant monetary exchange rates and sector aggregation [Weber, 2008]. Besides, the imputations techniques to construct trade-flow matrices, not apparent in IO models, bring extra uncertainty as well [Lenzen et al., 2010]. If you object to the assumption that errors are stochastic and uncorrelated, other methods become available, such as fuzzy logic analysis, entropy maximisation, or heuristic perturbation [Caggiani et al., 2014; Zheng et al., 2022].

Methodology

It is important to consider the origin of your errors (i.e. correlated or not) in your model to choose a sound method for an uncertainty analysis. With respect to this study, we adopt a blended view that a large part of the errors in the MRIO model are uncorrelated in nature, but we acknowledge that the construction of this study's trade relationships introduces correlated errors. The TFA assumes that the trade of intermediate and final adaptation goods follows the pattern of general trade flows. This TFA is constrained by the actual values of the adaptation dataset, where we choose not to deviate from. As a result, any stochastic variation in one trade flow coefficient affects others, thus introducing correlation between errors across the trade matrix. To account for this interdependence, we implement a heuristic perturbation logic. This approach introduces controlled variation by applying rule-based adjustments to the trade flows, rather than treating them as fully independent inputs. The rules applied are based on the limitations of TFA, refer to subsection 3.2.3. We apply heuristic perturbations that increase the share of domestically sourced adaptation goods and boost exports from three sectors in countries with hazard-specific expertise and exposure (recall the shift of comparative advantage). The selection of expert countries is primarily based on their extensive history of exposure to climate hazards, as further supported by external sources [STAR-FLOOD, 2016; Euro-Mediterranean Center on Climate Change (CMCC), 2025]. Three parameters are introduced, see Table 3.4. Two parameters focus specifically on flooding and heatwaves, as these two hazards account for the largest share of adaptation funding.

Parameter Name	Definition	Range	Countries	Sectors
Domestic Sourcing Parameter	Adjusts the share of adaptation demand sourced domestically vs. internationally. A higher value increases domestic sourcing, with trade coefficients renormalised.	0 to 0.25	All	Professional services Administrative and support services Other services
Flooding Expertise Parameter	Increases the export share of flooding-related adaptation goods and services from countries with high flooding exposure	0 to 0.2	Netherlands, Germany, UK Belgium	Professional services Construction Water & Waste Manag.
Heatwave Expertise Parameter	Adjusts the export distribution of heatwave-related adaptation from countries with high exposure and presumed expertise	0 to 0.2	Spain Italy Greece Portugal	Professional services Construction Water & Waste Manag.

Table 3.4.: Overview of adaptation-related GSA parameters used for perturbation

Aside from the correlated and stochastically bounded nature of the trade flow errors, we also account for uncorrelated errors in the Leontief matrix. Consequently, we follow the approach of Lenzen and Weber for Gaussian multiplicative perturbation [Lenzen et al., 2010]. The non-correlated and non-deterministic perturbation is applied to the Leontief matrix. Here, each coefficient is stochastically perturbed using Gaussian multiplicative noise with a standard deviation of 5%, clipped at ±5% to prevent extreme deviations. This approach simulates small-scale, non-deterministic uncertainty in input requirements.

The GSA is performed using the `EMA Workbench`, applying a Monte Carlo sampling method to run 500 simulations [Kwakkel, 2017].

4 Results

This chapter presents the key findings of this study. The results are organised into 3 subchapters, each corresponding to a research subquestion and applying a different MRIO technique. The findings are presented at both regional and sectoral levels, with a focus on public and private roles. All results are reported in 2023 purchaser terms. For the graphs of the years 2021 and 2022, navigate to Appendix N and Appendix O. Graphs are noted in nominal terms, unless there is a comparison over years or otherwise reported. For certain figures, ratios are used; although mentioned in the text, they refer to the equations presented in the previous chapter. The GSA is represented by either sensitivity ranges or shaded confidence bands in the plot. Although mentioned in each graph, a helpful tool is that graphs reported in green colours represent total adaptation summed across each hazard, while colour-coded graphs are disaggregated by hazard.

As reported in the previous chapter, the UK's FIGARO public trade flow coefficients have been replaced with those of the Asian Development Bank. France is excluded from the analysis since the trade flow coefficients were skewed towards imports and resulted in unreliable outcomes. This would have led to misleading interpretations. Lastly, Finland has been excluded from the analysis due to incomplete GVC computations, which resulted in distorted values.

4.1. CCA Output

Subquestion 1 aims to provide an initial insight into the total output of the CCA flows through the European economy. It will provide findings with respect to which countries, sectors, and hazards are most prominently involved in CCA activities. The findings are based on different aggregations, with each graph representing a distinct aggregation by country, hazard, supplying sector, purchasing sector, and type of demand (final vs. intermediate demand).

When keeping the data disaggregated by country and hazard, the results are diverse, see Figure 4.1. In nominal terms (i.e. bar charts), adaptation output varies significantly across countries. The five largest economies in Europe also rank as the top providers of climate adaptation goods and services. After normalising by total national adaptation expenditure (i.e. line), substantial differences occur. The output-expenditure ratio, see equation 3.19, ranges from 0.5 to 4.6, with most countries falling between 1.5 and 2.5. The ratios may have skewed estimates for highly open and small European economies, particularly those specialised in a single sector or with concentrated EU institutions.

Furthermore, Figure 4.1 shows that the primary focus of adaptation strategies in Europe is on heatwaves, followed by flooding. After a significant gap, the remaining investments are directed towards other hazards (e.g., windstorms, sinkholes), then wildfires, and lastly, drought.

Otherwise, when the purchaser, supplying sectors and the type of demand are kept disaggregated, the data reveal which sectors act as main purchasers, main final goods suppliers, and key intermediate input providers. Figure 4.2 shows the results for flooding and heatwaves, as these are the areas that account for the largest share of adaptation expenditures, as shown in Figure 4.1. The results for wildfires, drought and others are in Appendix G. Figure 4.2 is ordered from the largest purchaser sector to the lowest. Within flooding and heatwaves, the public is the largest investor of adaptation measures, followed by finance, other services and IT & communication. This pattern holds consistently across the hazards except for drought. Drought deviates from this pattern, where manufacturing emerges as the sector with the highest expenditure on adaptation. Regarding drought, solely agriculture, public and manufacturing are the main investors, see Appendix G.

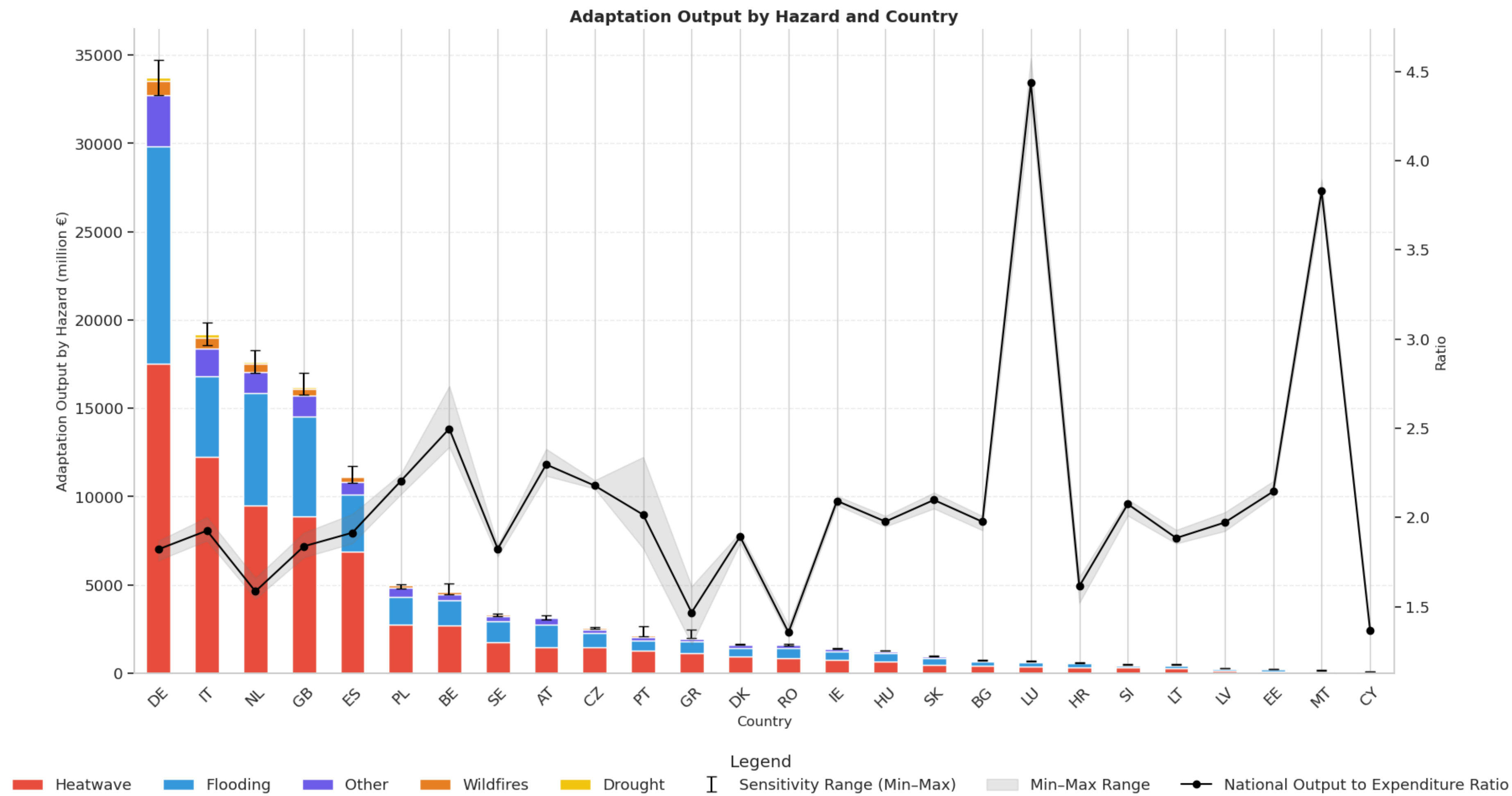

Figure 4.1.: Gross Adaptation Output per Country disaggregated per hazard denoted in million euros. The line represents the Adaptation output to Adaptation Expenditure ratio.

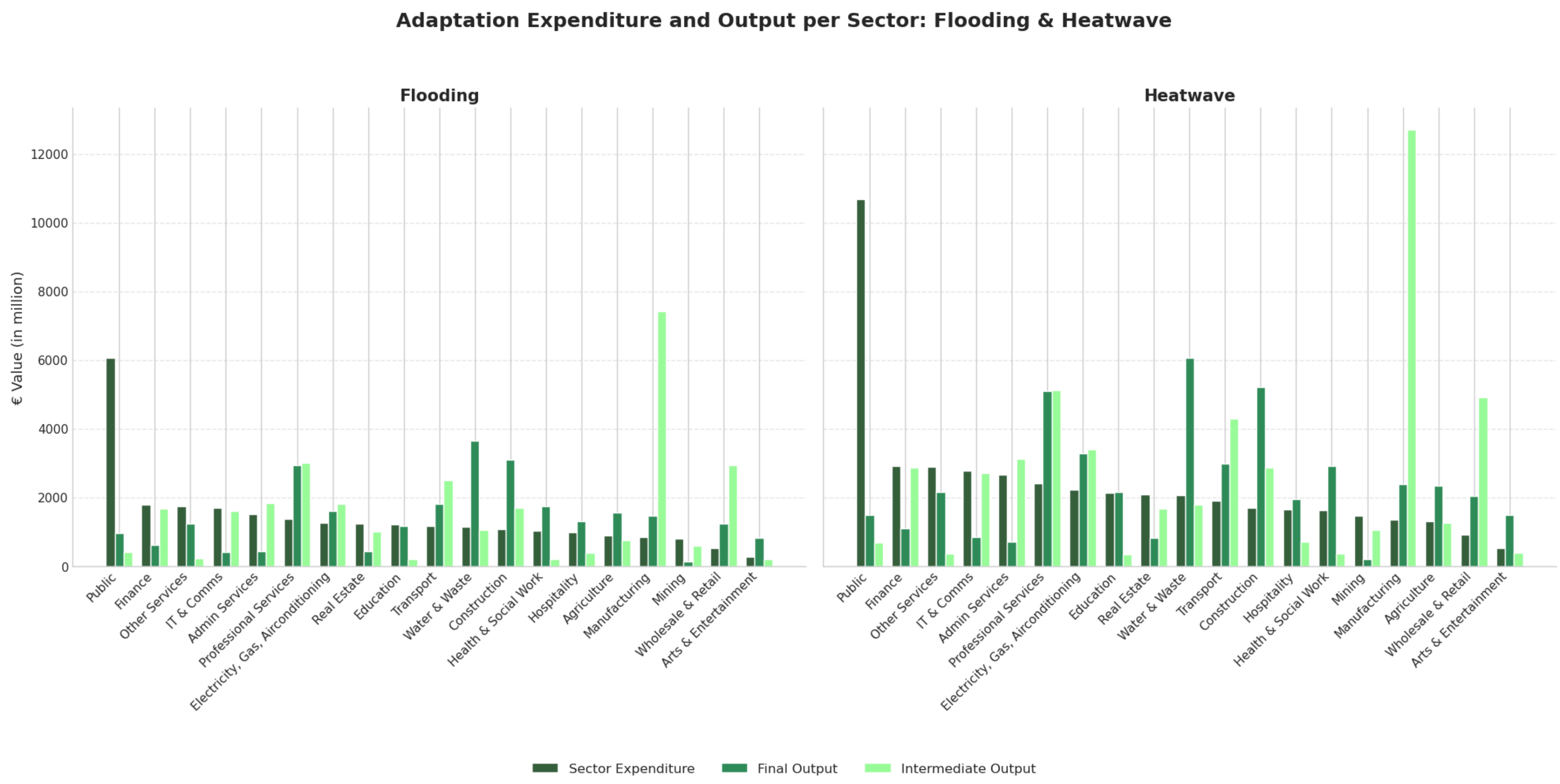

Figure 4.2.: Sectoral expenditure, - final output and - intermediate output denoted in million euros. Values are shown for Flooding and Heatwaves.

With respect to sectors supplying final adaptation goods or services, water & waste management, professional services, and construction are the most pivotal. The follow-up differs slightly per hazard, where the sectors of transport, electricity and health & social work alternate. This is a stable pattern across hazards, again, apart from drought. As for drought, construction, manufacturing, and agriculture are the only sourcing sectors. A final point from this graph is that manufacturing emerges as the key driver of intermediate output, not closely followed by wholesale and retail trade, and professional services. As can be seen, manufacturing is a vital underlying sector of the adaptation streams, with by far the highest gross output (both final and intermediate output). This is also true for professional services, which play a crucial role in delivering both final and intermediate goods.

After analyzing the contributions of individual sectors, it is also insightful to explore the differences between public and private investment patterns. This is particularly interesting in terms of where both the private and public sector source their adaptation products from. Figure 4.3 illustrates this, with the inner blue ring and percentage scores indicating the sectoral origin of final adaptation goods. As can be seen, the three main supplying sectors remain consistent across both public and private expenditures. The percentage scores across these three main sectors, however, differ. The percentage score for construction and professional services is higher for the private sector, whereas the public appears to allocate more expenditure towards the water & waste sector. Beyond these three main sectors, more differences begin to emerge. Public-oriented sectors such as health & social work, agriculture and hospitality show a higher reliance on publicly financed adaptation investments. In contrast, more private-oriented sectors, such as transportation and manufacturing, show a greater dependence on private funding sources. These differences in final adaptation expenditure diminish when we start looking at the main sectors involved in intermediate demand. Regardless of whether the adaptation goods are publicly or privately funded, the main intermediate input sectors remain largely the same, namely manufacturing, wholesale and retail, and professional services. A common underlying supply structure for adaptation products is not surprising, since the public and private expenditures flow to the same three main sectors.

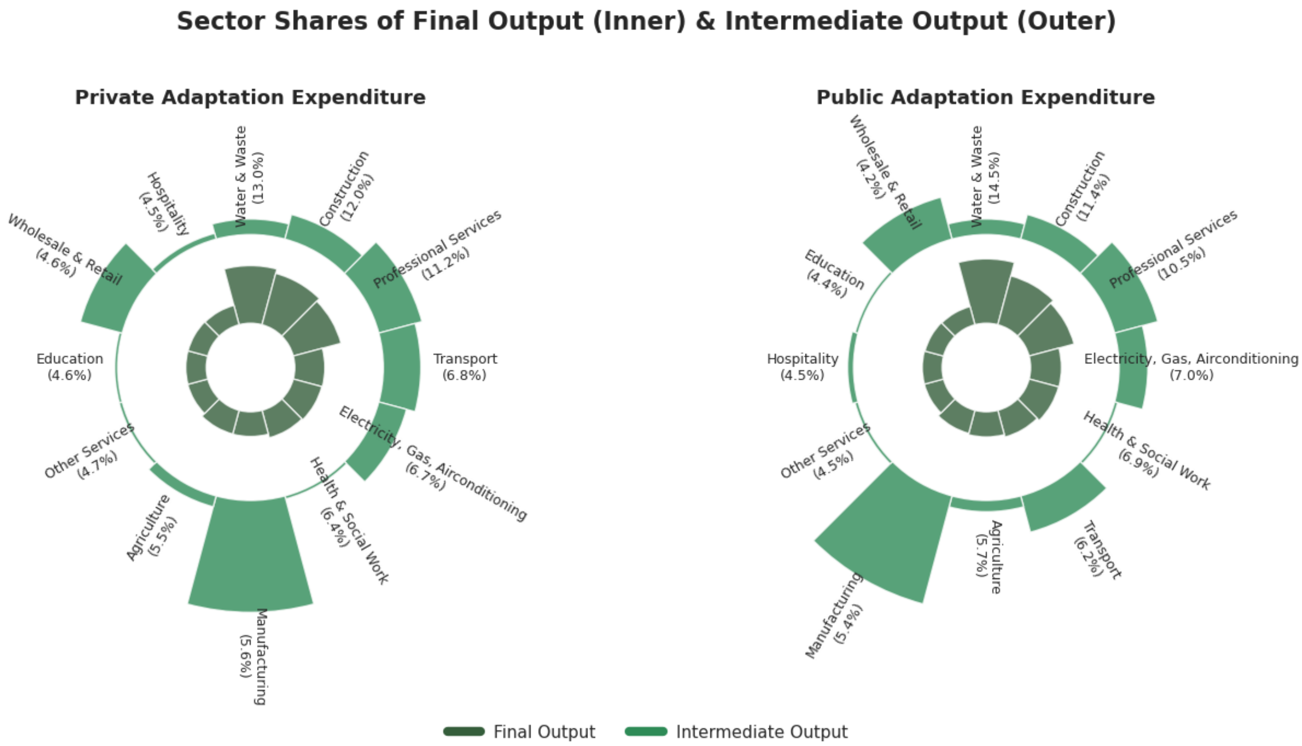

Figure 4.3.: Sector-allocation of the Private - and Public Adaptation Expenditure in percentages

4.2. Global Value Chains

Sub-question 2 aims to identify where adaptation investments generate value added. The analysis covers value added over time, by country, and by sector, each presented in separate graphs. A fourth graph illustrates the spill-over effects of CCA investments. To further explore these spill-over effects, a case study is performed, where the results are presented in an EU map and table.

Across years, the real value added creation of the adaptation investment is steadily increasing, see Figure 4.4. This graph ensures the stable increasing attention towards adaptation investments in Europe and the systematic approach of increasing adaptation investments.

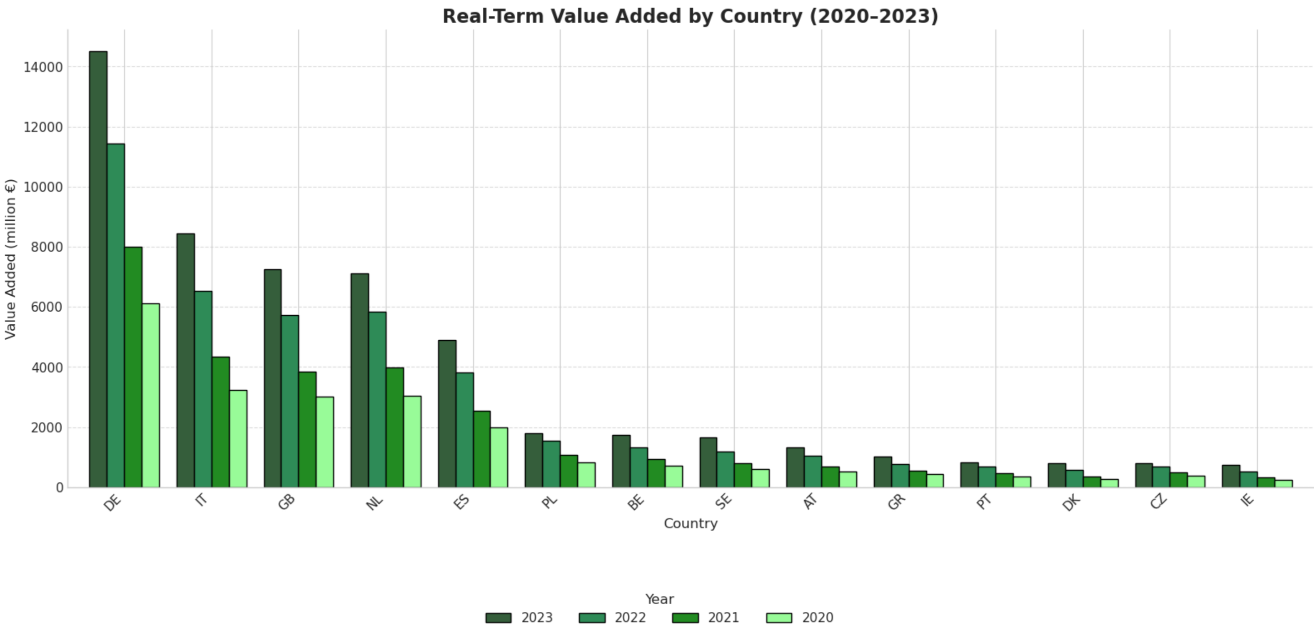

Figure 4.4.: Real Value Added of the top 15 countries from 2020 till 2023, denoted in million euros

Figure 4.5 shows the value added creation across countries. Most of the value added ends up in Germany, after a significant gap, followed by Italy, Great Britain, and the Netherlands. If you assess the value added generated by CCA relatively to the total GDP in the country, refer to equation 3.22 for details, it appears that the Netherlands, Greece, Croatia and Portugal score high. This suggests that adaptation-related activities are a relatively larger share of their domestic economies. This can either indicate a more domestic attention towards adaptation investments or the presence of key industries involved in exporting adaptation-related goods and services. As shown, the value added for these countries is mostly induced by domestic demand, suggesting a higher domestic attention towards adaptation investments. Ireland, Cyprus, Luxembourg and Denmark score below average. Conversely, this may indicate a higher reliance on imported adaptation-related value added or comparatively lower levels of domestic CCA expenditure. From small and highly open economies, such as Cyprus, this tendency can be expected. Ireland's values may be skewed due to its atypical value-added structure, in which a large share is induced by foreign demand, particularly from multinational corporations. As a result, the relatively low adaptation value may not reflect Ireland's actual adaptation efforts, but rather a misalignment between adaptation efforts and the national value added generation.

The value added creation across sectors can be shown in Figure 4.6. The value added earned across hazards and sectors mainly follows the pattern of the total output per sector. In consecutive order, manufacturing, professional services and water & waste are the sectors that earn the most on adaptation products, with the most value added created in heatwaves and afterwards flooding. The relative distribution across hazards remains consistent, with only some showing sharper increases or decreases. This is not the case for drought, mainly construction and manufacturing show high value-added generation.

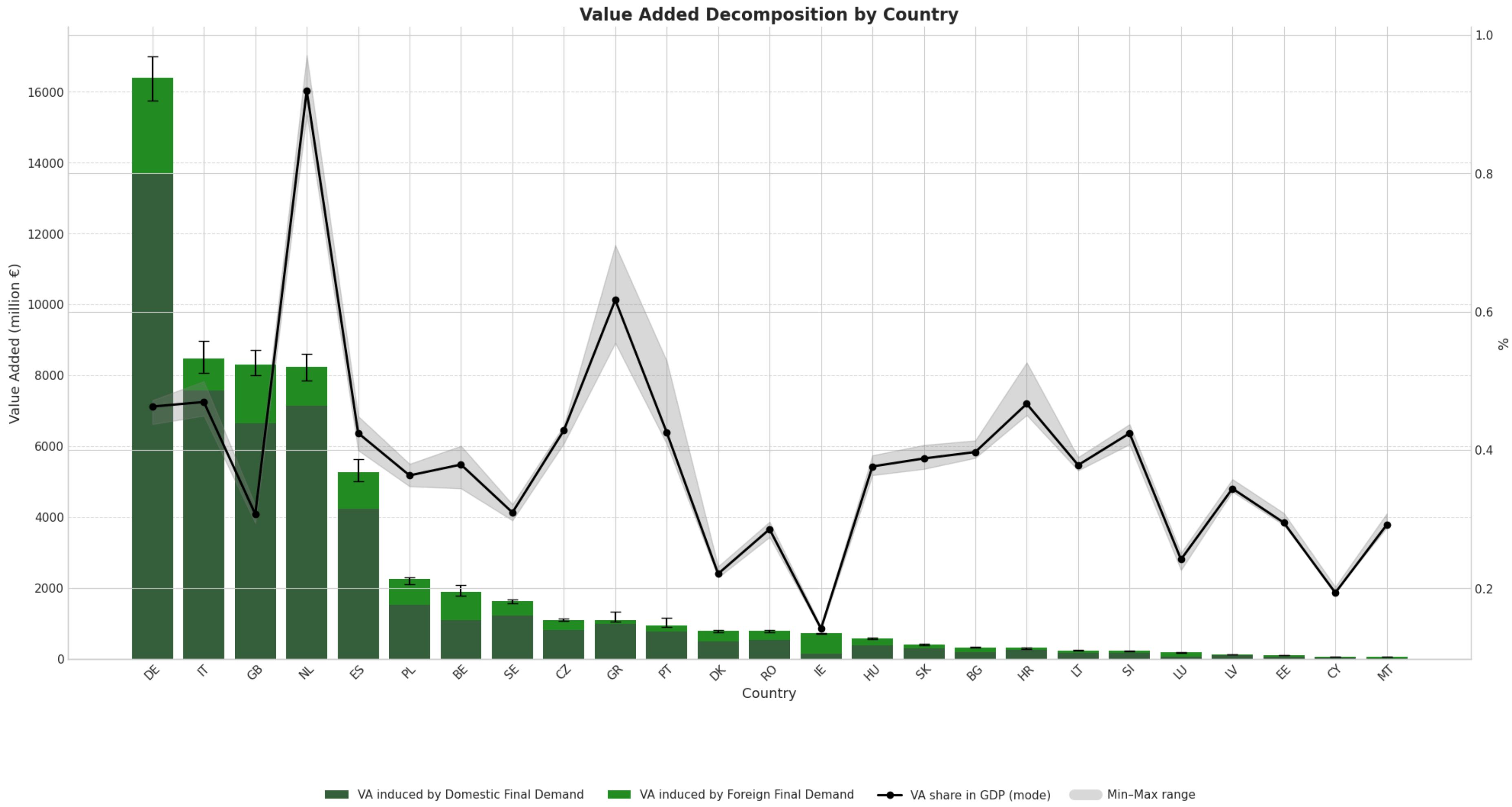

Figure 4.5.: Value Added distributed across sectors and hazards denoted in million euros. The bar charts represent the absolute terms (bar), and the line represents the relative terms of total national GDP (line).

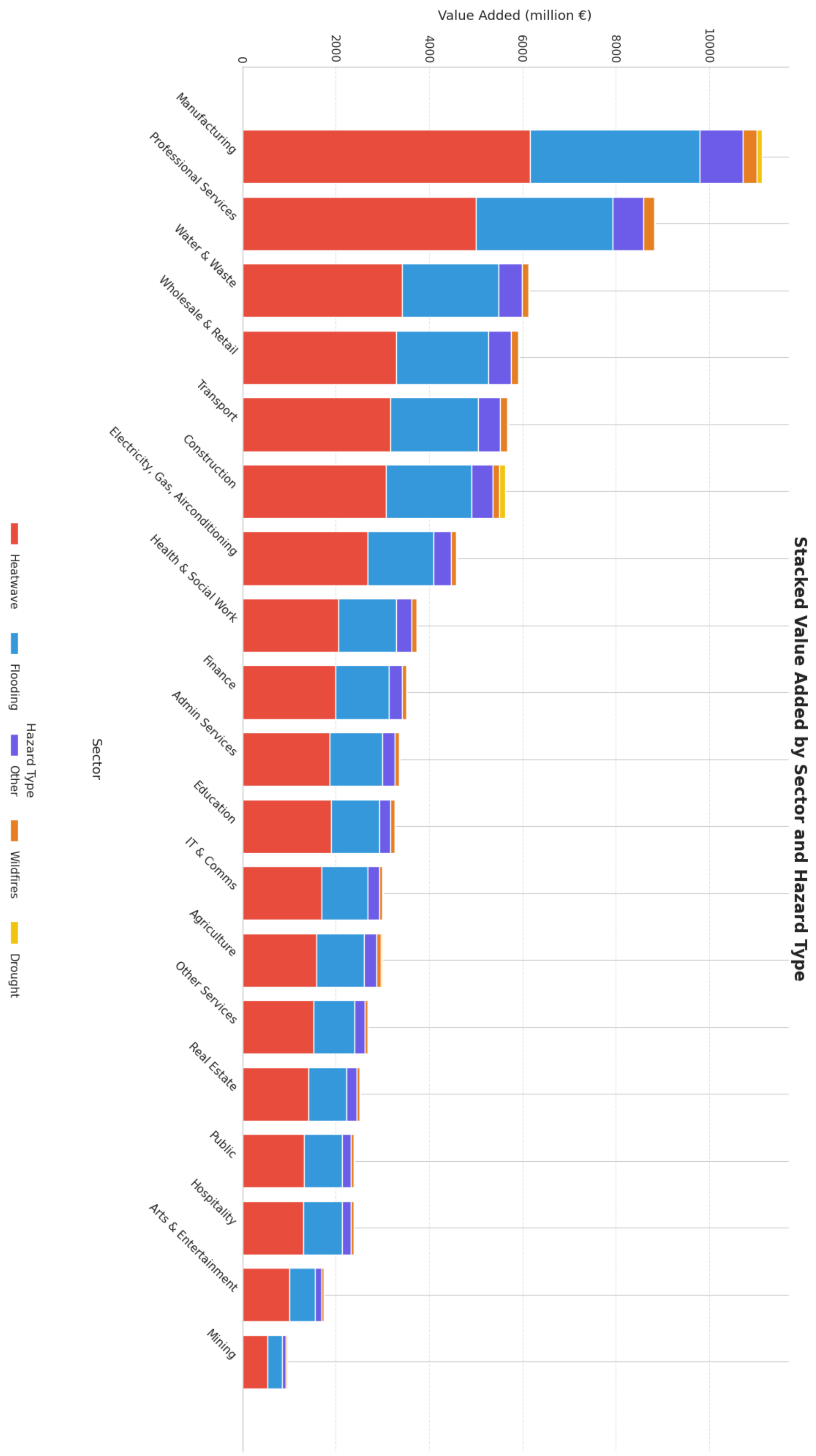

Figure 4.6.: Value Added Generation Per Sector and Hazard denoted in million euros

Till now, we have displayed, by following the GVC, the generation of value added across years, regions and sectors. In addition, it can be valuable to investigate in more detail the GVC themselves. Figure 4.7 illustrates how, along the global value chain, value added from CCA investments spills over to other countries, which captures the so-called spill-over effect. Great Britain, Italy, and Germany are countries that succeed in keeping the value added domestically. It is easier for larger countries to keep the value added domestically, since they possess more industries and resources nationally. Besides, we see that for Great Britain, a larger share of the leakage is directed to non-European areas, implying a more worldwide network.

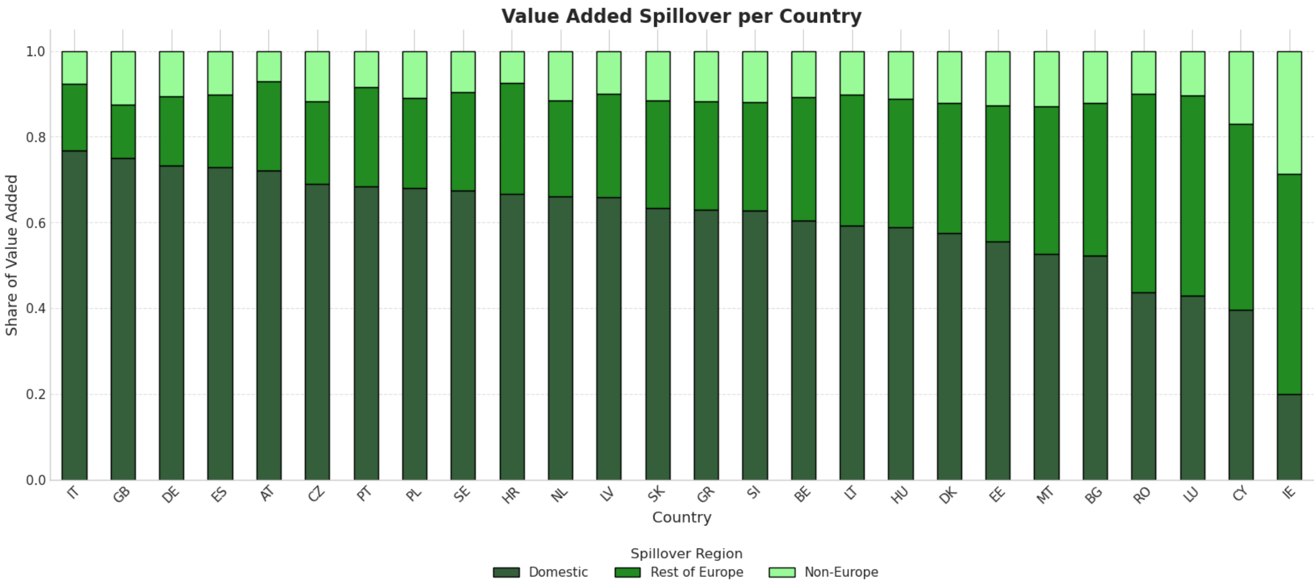

Figure 4.7.: Value Added Leakage Per Country as shares towards European or non-European countries.

To further explore these spill-over effects, refer to Appendix K, where a **case study** is conducted for Slovenia's LIFE4ADAPT project. As Slovenia exhibits an average level of spill-over effects compared to other European countries, it serves as a representative example of typical spill-over dynamics. The **case study** provides a more detailed description of the spill-over shares across European regions and non-European regions.

4.3. Domestic Value Added return

Sub-question 3 aims to mirror the value added generated against the initial adaptation investment. In contrast to the previous sub-question, which reported value added in absolute terms, this sub-question examines the value added in relation to the expenditure. This is done at the public and private levels, as well as at the sector level.

The differences in value-added return on a public or private adaptation investment, are shown in Figure 4.8. The DVA-return represents the generated DVA divided by its expenditure. It is close to an internal value-added multiplier, but applies a weighted average based on the final demand distribution. Figure 4.8 presents the DVA-return of the private and public sectors, excluding GSA effects, depicted as dark green and light green bars, respectively. Refer to Appendix L to see the DVA-returns when GSA is incorporated.

For the private DVA-return, most countries fall within a range of 0.35 to 0.75, with Ireland standing out. As with previous numbers, Ireland's value might be skewed due to the economic structure. The United Kingdom, Italy, and Spain show the highest values. As expected, the public DVA-returns are higher than their private counterpart. The returns generally range between 0.83 and 0.50, apart from Luxembourg. Italy scores the highest, followed by United Kingdom, Germany and Poland.

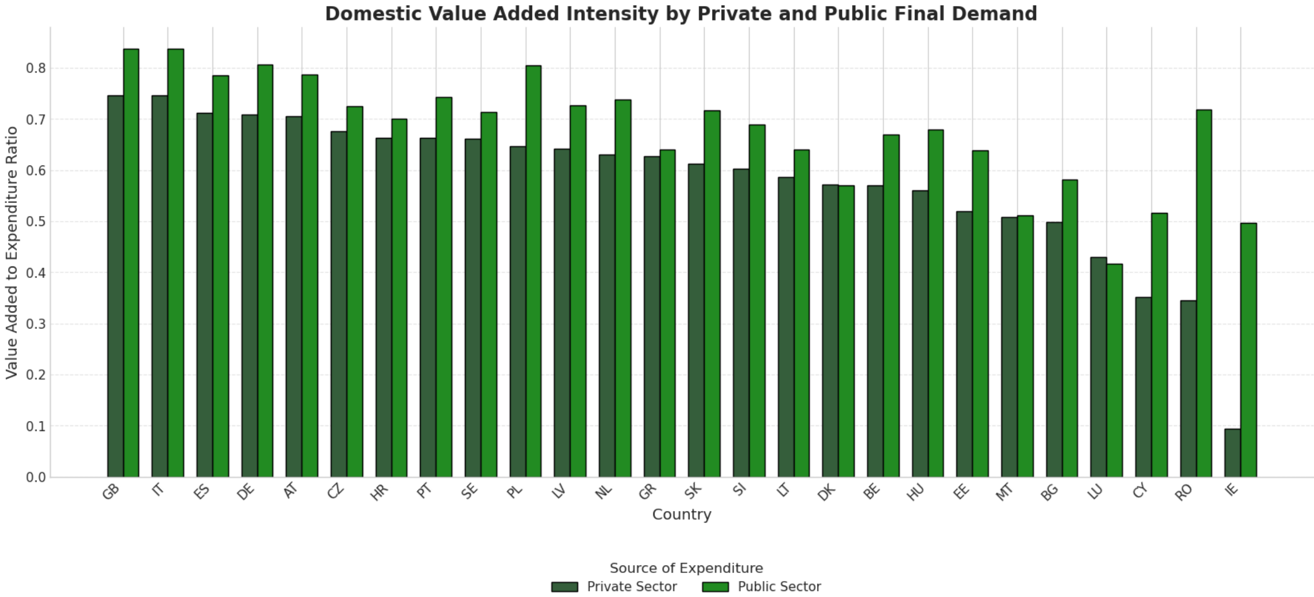

Figure 4.8.: Domestic Value Added return of private - and public sector as ratios.

Next to the differences in regional DVA-returns, it is valuable to assess the DVA-return of the different sectors, see Figure 4.9. The small EU member states, Cyprus, Ireland, Malta, and Luxembourg, were excluded from this sector analysis, as they would have a disproportionate effect on the values. Sectors with a high DVA-return include arts & entertainment, mining, and public services. The lowest domestic return is on wholesale & retail, manufacturing and construction.

Lastly, a full decomposition of the DVA-returns can be created. For this to succeed, a DVA of an adaptation investment needs to be disaggregated per hazard, per sector and country. This is done for flooding in Table 4.10. The table can be read as follows: The adaptation investments of Austrian agriculture in 2023 to combat **flooding** yielded a DVA return of 0.720. This would mean that 0.720 of the initial spending would generate value added back to Austria. Refer to Appendix M for the macroeconomic returns on heatwaves, wildfires, drought and other hazards.

Sector	Min	Median	Max
Agriculture	0.307	0.646	0.778
Mining	0.371	0.664	0.788
Manufacturing	0.459	0.619	0.721
Electricity, Gas, Airconditioning	0.366	0.627	0.743
Water & Waste	0.361	0.626	0.739
Construction	0.440	0.618	0.715
Wholesale & Retail	0.433	0.575	0.679
Transport	0.369	0.636	0.745
Hospitality	0.301	0.622	0.742
IT & Comms	0.335	0.643	0.759
Finance	0.325	0.643	0.761
Real Estate	0.252	0.646	0.766
Professional Services	0.333	0.646	0.758
Admin Services	0.331	0.641	0.757
Public	0.577	0.712	0.831
Education	0.326	0.645	0.763
Health & Social Work	0.350	0.633	0.746
Arts & Entertainment	0.311	0.686	0.781
Other Services	0.323	0.642	0.757

Figure 4.9.: Domestic Value Added return across sectors as ratios

Country	Agri	Mining	Manuf	Energy	Water	Constr	Retail	Transp	Hospit	ITCom	Financ	Estate	ProfSv	AdminS	Public	Educat	Health	Art	OthSrv
AT	0.720	0.737	0.669	0.691	0.695	0.671	0.626	0.708	0.696	0.716	0.721	0.714	0.707	0.709	0.765	0.708	0.699	0.783	0.719
BE	0.602	0.632	0.535	0.550	0.553	0.539	0.489	0.573	0.550	0.575	0.584	0.583	0.568	0.569	0.700	0.569	0.554	0.648	0.582
BG	0.493	0.442	0.511	0.531	0.519	0.509	0.403	0.552	0.523	0.491	0.490	0.474	0.481	0.492	0.597	0.488	0.530	0.502	0.479
CZ	0.711	0.716	0.641	0.672	0.670	0.642	0.626	0.675	0.669	0.682	0.688	0.685	0.675	0.677	0.727	0.676	0.673	0.776	0.684
DK	0.579	0.569	0.548	0.563	0.565	0.537	0.525	0.527	0.556	0.587	0.589	0.563	0.576	0.578	0.576	0.573	0.561	0.702	0.588
DE	0.750	0.716	0.689	0.710	0.713	0.689	0.598	0.706	0.715	0.711	0.719	0.734	0.702	0.708	0.798	0.705	0.718	0.743	0.710
EE	0.496	0.540	0.537	0.511	0.518	0.533	0.468	0.551	0.504	0.514	0.527	0.515	0.512	0.503	0.658	0.516	0.523	0.609	0.511
IE	0.083	0.095	0.094	0.093	0.090	0.107	0.007	0.097	0.116	0.091	0.091	0.112	0.095	0.092	0.497	0.088	0.086	0.058	0.101
GR	0.645	0.628	0.613	0.622	0.626	0.608	0.559	0.624	0.624	0.633	0.640	0.615	0.632	0.628	0.639	0.631	0.634	0.676	0.633
ES	0.759	0.761	0.694	0.705	0.705	0.693	0.663	0.703	0.711	0.712	0.717	0.728	0.705	0.709	0.773	0.708	0.709	0.781	0.711
HR	0.669	0.718	0.655	0.654	0.658	0.655	0.652	0.679	0.656	0.657	0.663	0.670	0.652	0.649	0.673	0.655	0.660	0.780	0.655
IT	0.767	0.755	0.719	0.740	0.736	0.707	0.650	0.756	0.726	0.764	0.763	0.749	0.748	0.757	0.831	0.755	0.743	0.773	0.761
CY	0.409	0.372	0.342	0.378	0.372	0.340	0.322	0.318	0.338	0.344	0.356	0.372	0.352	0.356	0.523	0.341	0.364	0.353	0.350
LV	0.651	0.644	0.608	0.635	0.623	0.618	0.527	0.641	0.623	0.658	0.667	0.638	0.657	0.651	0.713	0.659	0.629	0.615	0.661
LT	0.613	0.606	0.545	0.578	0.580	0.560	0.527	0.578	0.609	0.591	0.596	0.593	0.587	0.591	0.613	0.582	0.586	0.706	0.596
LU	0.417	0.522	0.455	0.393	0.394	0.485	0.338	0.456	0.418	0.425	0.433	0.439	0.432	0.413	0.431	0.432	0.399	0.348	0.430
HU	0.572	0.611	0.559	0.547	0.551	0.564	0.508	0.570	0.555	0.555	0.569	0.575	0.551	0.546	0.668	0.556	0.556	0.663	0.553
MT	0.546	0.559	0.479	0.495	0.494	0.476	0.460	0.513	0.486	0.509	0.522	0.514	0.508	0.502	0.574	0.511	0.498	0.616	0.514
NL	0.646	0.623	0.609	0.620	0.625	0.605	0.515	0.611	0.628	0.644	0.650	0.653	0.642	0.637	0.745	0.640	0.632	0.619	0.647
PL	0.656	0.674	0.637	0.644	0.650	0.629	0.605	0.670	0.634	0.643	0.652	0.650	0.641	0.641	0.771	0.641	0.652	0.697	0.646
PT	0.679	0.678	0.629	0.651	0.656	0.631	0.583	0.655	0.666	0.672	0.680	0.675	0.665	0.665	0.746	0.665	0.662	0.755	0.673
RO	0.278	0.332	0.451	0.376	0.363	0.431	0.435	0.381	0.282	0.330	0.328	0.255	0.345	0.330	0.711	0.344	0.360	0.332	0.318
SI	0.622	0.622	0.582	0.603	0.600	0.587	0.555	0.597	0.611	0.603	0.607	0.604	0.601	0.600	0.697	0.600	0.604	0.670	0.603
SK	0.629	0.669	0.600	0.620	0.616	0.606	0.565	0.643	0.616	0.602	0.608	0.630	0.597	0.598	0.694	0.599	0.618	0.690	0.601
SE	0.659	0.646	0.658	0.664	0.658	0.649	0.561	0.662	0.645	0.673	0.674	0.665	0.664	0.665	0.717	0.669	0.664	0.649	0.667
GB	0.788	0.750	0.711	0.740	0.739	0.713	0.603	0.734	0.747	0.758	0.766	0.769	0.752	0.753	0.796	0.753	0.748	0.790	0.761

Figure 4.10.: Domestic Value Added returns for Flooding disaggregated over countries and sectors

4.4. Global Sensitivity Analysis

The GSA was conducted to investigate how variations in input parameters affect key output indicators, specifically total CCA output and CCA value added. The goal was to assess whether minimal perturbations to inputs significantly alter the final model outcomes, thereby testing the robustness of the results. Two types of input perturbations were considered. First, stochastic perturbations were applied to Leontief inverses in the Leontief inverse matrix, simulating uncertainty in the backwards linkages. Second, heuristic, non-stochastic perturbations were applied to trade flow coefficients, reflecting correlated adjustments in trade patterns, particularly boosting domestic sourcing shares and exports from countries with hazard-specific expertise.

The analysis reveals that while output values do vary when inputs are perturbed, **the changes occur within a relatively narrow and dominant range**. This indicates that, despite changes in final demand inputs, **the structure of intermediate inputs is relatively stable and rigid**, resulting in overall outcomes that do not substantially shift. Other possible reason is that the sensitivity ranges of 0.2–0.25 may be set too low, or an insufficient number of simulations. Besides, **the sensitivity effects are more pronounced for the ratios of smaller countries included in the expertised groups**, such as Belgium and Portugal, as illustrated in Figure 4.2. This can be explained by the fact of non-proportional benefits of expertised countries compared to their national GDP or Gross Output. These countries experience relatively larger changes in output metrics due to input perturbations compared to larger economies.

Overall, despite a wide range of input parameter variations, the results remain robust within expected normal ranges. While there is a possibility of missing country- or sector-specific specialisations, the GSA suggests that the model's final outcomes are reasonably stable under varying input assumptions. The GSA can be improved by better assessing the specialisations and providing a more detailed final CCA demand distribution across Europe. These more granular findings can then be applied directly to the final demand matrix. Additionally, the number of simulations should be increased to more thoroughly explore the uncertainty space.

5 Discussion

The discussion highlights 5 critical findings. This discussion aims to situate these 5 empirical findings within the broader academic background. As for the first research sub-question, the findings can be compared to existing—though scarce—quantitative studies of adaptation efforts in Europe. Sub-questions 2 and 3 are situated within the qualitative literature and compared to findings from non-adaptation fields, as these results represent a novel contribution to the academic field.

After discussing the 5 critical findings, we will discuss the policy recommendations in the latest sub-chapter.

5.1. CCA Output

5.1.1 *Sub-question 1 confirms the findings of the scarce literature on final* CCA *gross output and extends these findings across a quantitative hazard-, sector-, and region-wise analysis across Europe.*

The results regarding the gross adaptation output show that across Europe, the total output is highest for **heatwaves**, closely followed by **flooding**. This aligns with the severity of these two climate hazards on the continent of Europe. According to the European Environment Agency, floods and heatwaves have historically contributed most to economic damages and fatalities [European Environment Agency, 2023]. The most recent European State of the Climate report highlights that in 2023, around 85% of the total estimated losses are attributed to flooding [Copernicus Climate Change Service, 2024]. It is therefore not surprising that most adaptation actions focus on these two hazards. Indeed, the same report states that most measures are taken with respect to flooding and heatwaves [Copernicus Climate Change Service, 2024].

As we have established that flooding and heatwaves appear to be the most climate-hazardous investments around Europe, it is no surprise that **the sectors of water & waste management**, **construction**, and **technical services** are the most sourced sectors across Europe. Compared across hazards, there are minor shifts in rankings; however, the sectoral distribution remains relatively stable: the same sectors consistently rank near the top, while other sectors remain at the bottom. The climate strategies of Europe's largest cities similarly highlight the importance of water-based solutions. Among 19.000 reported adaptation actions in European cities, actions regarding water solutions were most addressed 17% [Treville et al., 2022]. Besides, a study found that water & waste management attracted 50% of global adaptation finance, followed by agriculture, disaster risk management, cross-sectoral initiatives, and infrastructure and energy [Climate Policy Initiative, 2020]. The findings of current study support the reliance on water & waste management as adaptation suppliers, but also highlight a growing emphasis on physical measures (e.g. construction) and technical measures (e.g. professional services). This growing emphasis has also been observed in the European Copernicus study. According to Copernicus, adaptation actions in Europe were mostly identified as physical and technological measures 35.4%, followed by nature-based solutions 26.6%, governance 20.3% and knowledge-based 14.3% [Copernicus Climate Change Service, 2024].

If we start to distinguish **across EU-regions**, the five largest EU member states account for the highest levels of CCA output, while smaller member states produce the least. Notably, the Netherlands and Greece rank relatively higher than their economic size would suggest. This is supported by Appendix H, where both countries score the highest for CCA production relative to their national production. Apart from the smaller EU member states, Denmark scores relatively low regarding CCA output relative to their economic size.

5.1.2 *Sub-question 1 shows that CCA gross output figures are more diverse when examining: intermediate sectors of CCA output; analysing public and private induced CCA output; or when mapping the CCA output relative to their CCA spending.*

Looking at the broader economy, including **intermediate output**, **manufacturing** emerges as a key sector. Most intermediate products used in adaptation goods, across all five hazards, are predominantly supplied by the manufacturing sector, see Figure 4.2. Additionally, professional services play a significant role in providing intermediate inputs. Analysing the overall structure of the economy behind CCA investments, we can see that manufacturing, professional services and water & waste management are the pivotal sectors.

There appear to be differences between **public and private CCA efforts** in terms of sectors sourced. The top three sectors are the same for both; however, the shares differ. Water & waste management solutions are a larger share in the public adaptation efforts compared to private efforts. In some European countries, water & waste management are centralised, which requires more public consultation. Another possible explanation is that water & waste management solutions often require significant resources and generate broad public benefits, making them more dependent on public funding. In contrast, construction and professional services consist of a larger share of private efforts. Additional distinctions emerge beyond these three main sectors. Public CCA tend to involve more publicly oriented sectors such as health and social work, (regulated) energy activities, and agriculture. In contrast, private CCA efforts show greater investment in private-oriented sectors like transport and manufacturing. These preliminary findings therefore suggest an efficient adaptation approach, which argues that the public sector should mobilise private actors where market returns are there, while pursuing joint adaptation efforts in the most affected societal sectors, such as public health and safety [Massetti and Mendelsohn, 2018].

As mentioned above, the absolute and relative CCA output numbers with respect to the total national output are generally in line with the size of the European economies. If we start to map the **Output to Expenditure Ratio**, refer to equation 3.19, the numbers narrow between 1.5% and 2.5%, with exceptions for the smaller EU-member states of Cyprus, Luxembourg and Malta. Note that these numbers should not be confused with output multipliers, since these metrics do not analyse the total output of an initial domestic spending, but assess the total output induced by both domestic and foreign demand, divided by their national expenditure. Exports play a crucial role in this metric. This explains the larger ratio for Luxembourg, where their national spending is disproportionate to their financial services exports. More interestingly, is the relatively lower score of the larger EU member states of Romania, Greece and the Netherlands, where the total produced adaptation output, relative to their expenditure, is lower. The lower scores for Greece and the Netherlands can be explained by a higher relative spending on CCA compared to other countries, reducing the ratio. Besides, both countries share a relatively high import ratio compared to other countries, see Appendix H.1. Greece, as can be seen in Figure 4.5, has in addition very few exports. For Romania, it can be explained by a relatively low domestic production and a high relative import, as also shown in Appendix H.1.

5.2. Global Value Chains

5.2.1 *Sub-question 2 maps the CCA Global Value Chains across Europe, highlighting relative national differences in value-added generation, as well as identifying the key sectors contributing to this value added*

The total **national adaptation investments** tend to generate generally **between 0.2% and 0.6% of the national GDP**, refer to equation 3.22 for the equation details. A substantial outlier is the Netherlands, where adaptation efforts generate 0.9% of the national GDP. This is not surprising, given their long-standing experience with flood management and the substantial national funds already allocated to flood-related efforts [Dutch Ministry of Infrastructure and Water Management, 2021]. Greece and Croatia show high relative value-added figures as well. As illustrated in Figure 4.5, Greece's adaptation-related value added is mostly generated through domestic final demand. This indicates that domestic investment, rather than export-oriented activities, drives their adaptation sectors. The relatively high value added observed in these countries suggests a higher national attention towards adaptation. In the case of Greece, this aligns with estimates from its NAS, which recommends allocating up to 1.5% of GDP to adaptation efforts [Bank of Greece, 2016]. While national spending levels alone may not determine value added, as it can potentially leak to other regions, higher domestic investment tends to increase nationally embedded value chains and increase the economic returns within the country. Croatia seems to have a large export share relative to their national exports, see Appendix H.1. Ireland's low value-added figure diminishes when these figures are viewed in proportion to the overall economy, driven by multinationals. Despite the country-level differences, the value added generation of adaptation investments in absolute terms is growing systematically over the years, see Figure 4.4. Due to data constraints, this study assessed solely the intra-EU exports, meaning that the overall national GDP generation could potentially be higher.

Across sectors, as can be seen in Figure 4.6, it is evident that the **same sectors consistently generate the highest value added** across different hazards. While public and private adaptation investments are concentrated in three key sectors, the value added is distributed more evenly through their backwards linkages. The sectors manufacturing, wholesale and retail, and transport emerge as intermediate actors that benefit from CCA-related demand. Including both intermediate and final value added, the top five sectors are: manufacturing, professional services, water and waste management, wholesale and retail, and transport. Two reservations must be made: first, there is a potential caveat regarding the allocation of services, particularly within the professional and public sectors. For example, in sectors like construction, services may be embedded in the construction output, rather than being recorded separately under public administration or related service sectors [Miroudot and Cadestin, 2017]. This can lead to underrepresentation of the public or private services and overrepresentation of, for instance, construction in value-added statistics. Secondly, the purchaser terms are treated as full expenditure in the backward linkage, without subtracting margins and net taxes from the final demand expenditures. Using basic terms could lead to partially shifted patterns in the allocation of value-added across sectors.

5.2.2 *Sub-question 2 identifies preliminary findings that CCA investments result in spill-over effects, but less intensive compared to general economy investments and indicates that CCA investments are sourced from more domestically oriented sectors.*

Economic studies demonstrate that in highly open economies, a portion of the increase in final demand spills over to foreign countries. For instance, it is found that fiscal expenditure multipliers are smaller in countries with highly open economies (trade-to-GDP 60%), because much of the stimulus stimulates foreign production rather than domestic output [Ilzetzki et al., 2013]. This analysis has indeed found that the biggest leakages of adaptation investments appear in the highly open economies. As seen in Figure 4.7, countries as Ireland, Cyprus, Luxembourg and Malta score low on DVA generation on the national level. **The larger European countries have smaller leakage effects**. Italy, the United Kingdom, Germany and Spain, as can be seen in Figure 4.7, possess adaptation-relevant sectors domestically and can retain a greater share of value added within their own economies instead of relying on foreign inputs. Interestingly, Austria, Portugal and the Czech Republic have relatively to their country size low spill-over effects.

The findings suggest **spill-overs are less extensive in CCA investments**, and CCA investments appear to be **sourced from domestically oriented sectors**. Apart from the four smaller EU member states, the share of the total value added that is induced by CCA exports appears to be lower compared to the composite of general economic investments. The analysis, without the GSA, showed that the share of value added induced by European foreign final demand in total economic activities is 29% for Germany, 24% for Italy, 38% for the Netherlands, 39% for Belgium, 25% for Spain, and 22% for the UK, see Appendix J and also validated by [OECD, 2025]. In contrast, the shares for CCA-related investments, as shown in Appendix J, are lower: 18% for Germany, 11% for Italy, 14% for the Netherlands, 20% for Spain, 43% for Belgium, and 20% for the UK. This gives a first impression that the composite of CCA investments is more sourced from domestically oriented sectors compared to the composition of general EU investments. This is not surprising, since the final demand of construction, professional services and other services in general play a vital role in limiting GVC participation and exports [Cigna et al., 2022]. In contrast, the sectors that have high GVC participation and exports in major EU economies are: machinery and transport equipment (38.8%), manufactured goods (16.6%), chemicals (14.7%), food, drinks and tobacco (7.3%), and energy products (5.8%) [Alatriste-Contreras, 2015]. These sectors are less active in the CCA-investments and can explain the lower GVC participation.

Besides, a significant portion of total adaptation spending originates from public sources. Public CCA efforts are more domestically oriented and restrict the extent of cross-border trade.

The case study of Slovenia shows even more insights. As can be seen in Figure 4.7, Slovenia exhibits an average level of spill-over effects compared to other European countries; it serves therefore as a representative example of typical spill-over dynamics. The LIFE4ADAPT project in Slovenia, where the EU co-funded €14,177,980, demonstrates that adaptation investments in one country can generate value-added benefits across other countries. It shows that around 38% of the value added leaks outside Slovenia, refer to Appendix K. Besides, it is shown that China, Germany and Italy are gaining the most from the LIFE4ADAPT, see Table K.2. However, within the EU (19%), only Germany (4.2%) and Italy (3.4%) appear to generate a noteworthy share of value added from the initial EU investment. The European gain starkly contrasts, as we compare these numbers with spillover effects of the EU Structural funds, the structural fund spillovers appear to be above 25% for Europe [European Union, 2003]. A good reason for this is that structural funds were primarily oriented towards infrastructure projects, which generally possess longer backwards linkages. A study that made the distinction between developed and less-developed regions receiving the Cohesion Fund, found that even in less developed regions the spillover can be more than 30% and in some countries even more than 40% [Römisch, 2020]. If we take the spill-over effects of the Next Generation EU stimulus, a study of the ECB found that around a third of total output is activated due to spillovers [Pfeiffer et al., 2023].

These preliminary findings provide valuable insights, but they also come with limitations. First, the GVC are compared as composites—CCA investments versus economy-wide investments, rather than at the sectoral level. As a result, we can only draw conclusions about the domestic orientation of sectors involved in CCA investments, not the actual length or domesticity of the individual supply chains. While the data suggest that CCA investments are more concentrated in domestically oriented sectors, they do not clarify whether specific sectors—such as finance—are actually more domestically oriented regarding CCA efforts. Moreover, the sector categories used are too aggregated to capture meaningful variation in GVC positioning. For example, categories such as wholesale and retail, or machinery, can vary significantly in their position within GVC when considering specific adaptation products, such as early warning systems or rain barrels.

5.3. Domestic Value Added return

5.3.1 *Sub-question 3 reveals the national value added return of CCA investments (i.e. DVA), which appears to be comparable to that of general economy internal value added Leontief multipliers.*

Figure 4.8 shows the DVA returns by national public and private CCA investments. It becomes evident that **publicly initiated investments** tend to **generate higher levels of DVA** than their private counterparts. This observation is consistent with Ramey's assessment that government investment can have more substantial effects on economic output compared to private investment [Ramey, 2019]. In addition, it is interesting to see that Austria, Portugal and Croatia score high with domestic returns within the private sector. Regarding the domestic value-added return within the public sector, Great Britain, Italy, Germany and Poland score high.

If we start looking at comparable studies employing Leontief multipliers derived from MRIO models focusing mainly on short-term direct and indirect effects, **the DVA returns appear to fall within the same range** [Stehrer et al., 2024]. The results across countries are largely consistent with the previous study. Italy and Great Britain record the highest scores, followed by Spain and Germany. Portugal, Austria, Sweden, and Greece also perform well in both studies. Notable exceptions include Romania and Cyprus, which ranked high in the previous study but significantly lower in this study. This difference may stem from the previous study not distinguishing between private and public spending. In the current analysis, Romania's public score remains high, reaching approximately 0.72. Countries such as Belgium, Denmark, Bulgaria, Hungary, Estonia, Luxembourg, and Malta consistently show low scores across both studies. Exceptions include the Czech Republic and Croatia, which show relatively high scores in the current study compared to the previous study. A reason for this can be the methodological approach. Although both studies make use of MRIO multipliers, a key distinction of this study is the incorporation of the CCA final demand matrix into the calculation of the DVA metric. In contrast, traditional Leontief multipliers rely solely on the intermediate input matrix. This represents a significant methodological approach, as the DVA-return allows the analysis to capture value added driven by final demand, not just intermediate production linkages. This implies that the weights of CCA final demand per sector are incorporated, and can differentiate the results between the studies. From this, we can conclude that the distribution of final sourced adaptation products and their corresponding backwards linkages closely mirror the EU economy's backwards linkages. The differences can be explained by methodological approaches and the national differences in CCA strategies.

5.3.2 *Sub-question 3 demonstrates that disaggregating DVA returns by sector, hazard, and country reveals greater diversity in outcomes. These disaggregated results can serve as estimations for the economic co-benefits within MCA.*

The composite of publicly or privately financed CCA appears to yield solid domestic returns, **there are however notable differences in the sectoral composition of these CCA efforts**. To see the differences, refer to Table 4.9. Certain sectors—such as the public, art & entertainment, mining and services—tend to generate particularly high DVA when they invest in adaptation. Besides, finance adaptation investment yields high DVA returns. In contrast, sectors such as wholesale & retail, manufacturing and construction have a lower DVA return. That these sectors score lower on domestic return is not surprising, since these are also the sectors that play a more prominent role in GVC participation [Alatriste-Contreras, 2015]. The returns across sectors in the MRIO model also align with previous Leontief studies [Stehrer et al., 2024; Kratena, 2024].

If we completely disaggregate the DVA-returns, per hazard, sector and country, we obtain very detailed and varied outcomes, see for the hazard of flooding, Figure 4.10. Navigate to Appendix M for the hazards of heatwaves, wildfires, drought and other. These findings present, for each sector within a given country, the domestic value-added return in response to a specific hazard. For instance, when the energy sector of Belgium invests in flooding CCA, the macro-economic return appears to be around 0.55, whereas in Great Britain the value added return is around 0.71. These macro-economic return figures can be used for guiding CCA decision making; further details are provided in the *Policy- & Research Recommendations* section.

The implications of DVA returns and broader public investments in CCA warrant further analysis to better understand their role in guiding effective CCA decision-making. As with general public investments, publicly financed CCA investments provoke questions about their broader economic impacts, an area that has long been debated in macroeconomic literature. In the short term, it is widely accepted that non-taxed public spending creates value added and stimulates economic growth [IMF Research Dept., 2012; Auerbach and Gorodnichenko, 2012]. However, a more theoretically grounded debate concerns how these effects of public expenditure evolve over the medium and long term. Scholars generally agree that fiscal multipliers are effective in the short term, but their impact may diminish over time, as rising capacity utilisation triggers inflationary pressures and monetary policy adjustments, as suggested by Neo-Keynesian and Neo-Classical frameworks [Kilponen et al., 2015; Cwik and Wieland, 2011; Grady and Muller, 1988; Hughes, 2003]. They argue, and also demonstrated in empirical work, that if the Taylor rule is applied, the fiscal multiplier will be (partially) absorbed by the interest rate [Hagedorn et al., 2019]. However, several studies—including those by the IMF and analyses across OECD and Eurozone countries - find that well-designed public investments, particularly in infrastructure, can yield positive effects even in the medium to long term [IMF Research Dept., 2012; ADB et al., 2016; Deleidi et al., 2023; Saccone et al., 2022]. A key reason these studies differ lies first of all in their methods and theoretical frameworks used, but also in the absence of ceteris paribus conditions. The effectiveness of public expenditure depends, among others, on the state of the economy at the time of implementation; accommodative monetary policies; country; and type of investment [de Jong et al., 2017; Ramey, 2019]. Besides, it is based on the type of financing. A debt-financed multiplier enables the entire stimulus to flow into the economy, leading to a larger multiplier effect [Gechert and Rannenberg, 2018; Saccone et al., 2022]. In contrast, tax-financed public expenditure involves an immediate increase in taxes to fund spending. This can make the multiplier twice as small compared to deficit-financed [Hagedorn et al., 2019]. These differing findings might question the actual impact of the general public stimulus as well as the adaptation-oriented stimulus.

In light of these considerations, the effects of public CCA investments should be interpreted carefully. First, it is good to restate that the DVA-returns are MRIO estimations and thus do not capture dynamic behavioural responses, time lags, or the influence of monetary policy, nor do they fully account for the timing within the cyclical phase of the economy. Second, studies are showing mixed results for these investments in the mid to long term, which can be attributed to the timing, scope, and methodology of the studies. Fortunately, these reservations may be less relevant when considering CCA investments. CCA should move forward regardless of broader economic conditions, such as interest rates or economic cycles; the key is to select and prioritise CCA interventions that deliver the greatest overall value on all three dividends. As for this reason, the economic multiplying effects of CCA should be compared to each other within a MCA rather than evaluated over time, methodology or ceteris paribus conditions.

5.4. Policy & - Research Recommendations

The findings of this study can be used in multiple ways to enhance CCA strategies and improve the CCA decision-making. The 5 critical findings can be translated into 3 policy recommendations for CCA decision making, with attached directions for further research.

5.4.1 *Strategic policies should target pivotal sectors such as water & waste management, manufacturing, and professional services to de-risk private investment and unlock systemic CCA efforts.*

One way to improve CCA decision-making is by developing market instruments or industrial policies for pivotal CCA industries that can stimulate private CCA. This is, for instance, initiated by the Climate Policy Initiative, to investigate industrial policies within the sector of water & waste management [CPI, 2024]. Current study confirms the importance of water & waste management in sourcing CCA solutions to both the private and public sector. In addition, this study showed that the sectors of manufacturing and professional services also take a large share of the CCA output. These sectors appear to be important across multiple hazards, across different sourcing sectors and different European countries, and could be a potential target of a systemic intervention to enable more private CCA efforts. It might therefore be valuable to research further the possibilities of industrial and finance instruments directed towards these pivotal sectors.

A considerable amount of research has been conducted on market instruments aimed at unlocking private and public CCA. Most of these studies have focused on soft governance instruments to mobilise CCA, such as raising awareness, improved risk assessments, and knowledge-sharing platforms. These policy interventions primarily target **autonomous CCA**, aimed at micro, small, and medium-sized enterprises (MSMEs), since limited awareness and access to information are key barriers for these actors [Schaer and Kuruppu, 2018]. Other studies took it one step further and looked into the potential of financial instruments, such as blended debt, green bonds, sustainability-linked-bonds, results-based financing and guarantees [Worldbank Group, 2021; OECD, 2024a,b; Brown, 2022]. These financial tools are primarily aimed at unlocking capital or reducing investment risk in large-scale CCA projects, but can also be used in autonomous private CCA. These financial instruments must be tailored to the type of actor involved. For large-scale investors, the focus should be on reducing the weighted average cost of capital (WACC), using tools such as blended finance structures, first-loss capital, or guarantees. In contrast, when supporting MSMEs in undertaking private CCA, industrial policies—such as targeted subsidies, tax exemptions or preferential procurement—may be more appropriate.

This study contributes to this discussion by identifying three sectors—water & waste management, manufacturing, and professional services—that are structurally central to CCA output. In line with Climate Policy Initiative, the role of these pivotal sectors to unlock private CCA should be further investigated [CPI, 2024]. For instance, by targeting these sectors with tailored industrial or financial policies, private CCA activities can be more efficiently mobilised. Moreover, the findings can inform the design of de-risking measures—such as subsidies, tax exemptions, or below-market financing—specifically aimed at mobilising private investment in these key sectors [Worldbank Group, 2021]. To apply this approach effectively, it can be fruitful for further research to delve deeper into the literature on industrial policies. Additional insights can be drawn from experiences in climate mitigation, which offer useful lessons on mobilising the private sector in transformational change.

5.4.2 *The limited and uneven economic spillovers, in line with the domestic nature of CCA investments, complicate solidarity EU-coordination on a large scale. Yet, climate change is likely* *to widen European inequalities, highlighting the need to improve the design of these direct funding programs or explore new ways of EU CCA coordination.*

Supranational adaptation governance in Europe remains in its early stages. As highlighted by Biesbroek et al. [2010], the EU has predominantly relied on soft governance tools—such as knowledge-sharing platforms and policy mainstreaming—to support national adaptation efforts. The EU lacks the mandate and financial instruments to fund adaptation across member states, which results in CCA efforts that are framed as a local or national responsibility. Coordination efforts have mainly focused on cross-border hazard regions, with transnational adaptation initiatives established in areas such as the Alpine region, the North Sea, the Baltic Sea, the Baltic States, and the Atlantic area [European Environment Agency, 2018; Roggero et al., 2019]. One of those coordinating examples is Slovenia and Italy's flood protection infrastructure, illustrating the cross-border benefits of targeted CCA. However, evidence suggests that only about one-third of such transnational initiatives fully achieve their outcomes [Dzebo, 2019].

The examples above concern transnational regions where both neighbouring countries are exposed to a similar climate hazard. There are fewer examples of solidarity or direct funding schemes within the EU where vulnerable national regions are supported by EU. This limited coordination is done mainly for nature-based projects, that is co-funded by the EU from non-CCA-funds as the LIFE Programme or ERDF. Yet, the results of this study complicate direct EU funding as a systematic solution for the increasingly needed resources of climate impacts. It has been shown that the value added spill-overs appear to be structurally lower than the general economy investments. The spill-over effects, as shown in Figure 4.7, have also been compared to previous solidarity schemes, and seem to be substantially lower. Although there is no alignment on spillover minimums to justify solidarity co-funding, these preliminary findings make it more difficult to justify the creation of systematic co-financing mechanisms on a large scale. Lastly, as shown in the case study in Appendix K, a big share of value-added leaks to non-European regions, such as China and the Rest of the World (RoW), which makes it harder to support solidarity-based contributions. Solidarity funding, or direct funding, will therefore provoke problems when CCA efforts need to be upscaled.

Yet, given the substantial rise of climate impacts and the interdependencies between European economies, systematic EU coordination is warranted [European Environment Agency, 2024a]. This becomes even more urgent, given the IPCC's warning that climate change is likely to widen economic disparities across Europe. Southern regions are probably facing disproportionately larger losses, and northern regions may experience limited benefits [Pörtner et al., 2022].

So, with climate impacts and inequality rising across Europe, EU coordination where costs and benefits are shared more equitably across Member States becomes increasingly important [European Environment Agency, 2024a]. However, since CCA investments are sourced from domestic-oriented sectors and thus not creating extensive spill-overs, pursuing systematic EU-wide solidarity schemes seems, based on these preliminary findings, to be less suitable. Further research should therefore explore **improving the design of direct funding mechanisms** or find **new effective ways for EU CCA coordination**. These early insights can help improve the design of these CCA funding programs in Europe. The effectiveness of bilateral or conditional funding schemes, additional side-payments or partner agreements tailored to the characteristics of each project should be further explored. Conditions, such as requiring procurement from the contributing country, may also enhance political feasibility. For instance, future work could examine the design of conditional compensation for countries whose CCA investments provide measurable cross-border benefits, such as flood protection or energy grid stability.

5.4.3 *Research and practice should place greater emphasis on assessing multiple objectives of CCA investments—such as DVA-return—to support CCA decision-making through static or dynamic MCA.*

Justifying and prioritising CCA investments remains a challenge, particularly since resources remain scarce and the benefits of these interventions are often unobvious, long-term and highly uncertain [Hallegatte et al., 2012; Josephson et al., 2024]. Especially given the nature of both public and private CCA investments, which often require large upfront costs to protect against distant, low-probability events or long-term shifts in climate patterns [Fankhauser and Burton, 2011; Chambwera et al., 2014]. As a result, most of these CCA interventions are still seen as costs and not as benefits. Academics and key institutions, such as the IPCC, have therefore proposed prioritising adaptation investments based on a multi-criteria assessment [World Bank, 2024; Chambwera et al., 2014; Viguié and Hallegatte, 2012;

Pisu et al., 2024; Hallegatte et al., 2012]. A framework that has been proposed to justify and prioritise general CCA investments is the Triple Dividend Framework [Tanner et al., 2015], where the triple dividends are defined as: (1) avoided losses from climate impacts, (2) economic co-benefits such as increased productivity and employment, and (3) social and environmental benefits, such as improved health or equity.

This study contributes to the second dividend of this framework by assessing the macroeconomic returns of CCA investments. The metric DVA-return represents the value added returned to the domestic economy per euro spent on final adaptation demand for each individual hazard, see Figure 4.10. For example, if the Austrian Energy sector invests in flood adaptation products, it will approximately return 0.69 of its investment in DVA through backwards economic linkages. It is important to note that this represents only one element of economic benefit. Other factors, such as productivity increases, risk reduction, and innovation stimulation, also influence the total economic dividend but are not captured in this metric.

Germany provides a compelling case for applying this metric to MCA due to its detailed vulnerability assessments. Reports from the Umweltbundesamt classify climate impacts across 14 distinct sectors, over time (e.g., present, near future, distant future) and alongside qualitative national severity indicators (e.g., low, medium and high) [Buth et al., 2015]. Together with the results from the current study, this has the potential to identify CCA measures that perform well among those two objectives, as in this case: general vulnerability scores, and DVA-returns.

For example, with regard to the first objective of avoiding losses, heat stress represents a significant threat to the sector of human health. Other sectors with high vulnerability scores include industry, commerce, and construction, which are at risk from both river flooding and the challenges of maintaining indoor climate during heatwaves. In the transport sector, extreme weather increases the likelihood of damage to railway infrastructure. Similarly, the energy sector is exposed to reduced cooling capacity during heatwaves. As for the second objective, this study showed for Germany, that from these potential planned efforts, the sectors of energy and health under heatwave conditions provide high macroeconomic return. Based on these two objectives, CCA investments in the energy and health sectors appear promising and should be prioritised. While this assessment is simplified, realistic multi-criteria analyses (MCA) should incorporate a broader range of objectives, including avoided losses, productivity gains, background risk reduction, innovation potential, social benefits, and biodiversity outcomes. The DVA-return developed in this study can serve as one of several economic decision criteria within such an MCA framework.

Even more, this criteria can be applied in more dynamic decision-making strategies, such as robust decision making, scenario-based planning, real options analysis or adaptive pathways [Wilby, 2022; Hallegatte et al., 2012]. These dynamic searching strategies are essentially based on MCA; however, they try to optimise the solutions over scenarios and time. They are trying, in words of Hallegatte, to find the most **robust** CCA investment over the most **optimal** investment under one reference scenario [Hallegatte, 2009]. Adaptive pathways introduce an extra layer by incorporating a time component. It structures pathways, where certain CCA efforts can be scheduled or revisited depending on how risks evolve [Haasnoot et al., 2013]. This method of creating adaptive pathways for CCA, among others, proposed by the World Bank, requires expert insights of analytical tools for robust decision-making under uncertainty [World Bank, 2024; Wilby, 2022; Eker and Kwakkel, 2018]. Analytical tools, such as the minimax regret approach, can for instance, enhance this process [Chambwera et al., 2014]. It must be said that it requires a strong degree of expert judgment or participatory stakeholder engagement in defining appropriate weighting sets for the different objectives.

There is one additional feature to the metric of DVA-return. The insights can also inform the potential role of the public in financing CCA. When certain sectors exhibit high macroeconomic returns (i.e. a stronger DVA return) but are characterised by market failures such as public good externalities or coordination challenges, there may be a stronger case for public involvement. In these cases, the public sector could consider more substantial interventions, including joint adaptation planning, covering upfront costs, or offering long-term concessional loans. Conversely, for sectors where macroeconomic returns appear lower, it may be more efficient for the government to focus on low-cost, enabling interventions that **mobilise** private sector action. These kinds of actions could include raising awareness, improving risk information, or improving regulatory processes. If increased public intervention is needed in non-beneficial sectors, governments could explore public procurement strategies that prioritise domestic participation, thereby enhancing DVA.

In short, these CCA static and dynamic decision-making strategies encompass a broad range of objectives, and the DVA-return metric employed in this study can contribute as a macroeconomic objective to such multi-objective dynamic assessments. Besides, it can showcase whether to pursue substantial public interventions when there are high returns or instead pursue low-cost, enabling measures to mobilise private action when there are low returns. However, for this to happen, future research should focus on developing more comprehensive and policy-relevant metrics to evaluate the economic and social co-benefits of CCA. This includes incorporating financial gains from reduced background risk and increased productivity, which could offer more precise insights into the full value of adaptation investments. Such improvements would contribute to a clearer understanding of the total economic benefits. The same accounts for social - and environmental benefits, where objectives such as improved public health, enhanced social equity, increased green space and biodiversity preservation should be better assessed and integrated into decision-making. In addition to better defining and mapping co-benefits, both research and practice should aim to systematically apply static and dynamic MCA frameworks in CCA decision-making. While the application of these methods remains limited in the adaptation literature, they have shown effectiveness in other socio-economic domains and, where applied in the CCA context, have demonstrated promising results. Clear MCA are also needed to avoid maladaptation that could lock in vulnerabilities or lead to inefficient long-term outcomes, when for instance, the climate hazard does not materialise. With the climate events already rising, the deep climate uncertainty and the limited public resources, it is essential to carefully assess which CCA measures are most effective.

6 Conclusion

This study offers a novel contribution to the field of CCA by providing a quantitative assessment of how public and private CCA investments propagate through the European economy. This was achieved through an MRIO model that captures the sectoral and national dynamics of adaptation-related spending. The model integrates disaggregated CCA expenditure by hazard type, country, and sector with EU FIGARO trade flow data, and distinguishes between public and private investment channels. This methodological framework enables a more granular understanding of the macroeconomic footprint and value chain structure of CCA efforts across Europe.

The MRIO analysis generated findings, according to the sub-research questions, across three key dimensions. First, it identified the pivotal sectors involved in producing both final and intermediate CCA outputs that distinguish public and private investment patterns. Second, it accurately mapped the allocation of value added across countries and sectors. It provided outcomes on macroeconomic gains of CCA investments and their allocation along the value chains. Third, it introduced a precise and fully disaggregated DVA-return metric to evaluate the macroeconomic returns of CCA investments, offering insights into how final demand translates into domestic economic value.

Built on the strong empirical findings, this study has given directions for improving CCA decision-making. One direction is the development of adaptation-oriented industrial policies targeting key sectors—such as water & waste management—that play a pivotal role in both public and private CCA efforts. Besides, in light of IPCC's warnings about increasing climate disparities within the EU, this study assessed the potential of EU solidarity schemes. Systematic EU-wide funding schemes may be difficult to justify due to the large and diffuse variation in spill-over effects. However, bilateral coordination, side payments, and solidarity efforts could be further explored, as there appear to be spillover effects in Europe. Lastly, it provided a macroeconomic criterion for prioritising CCA efforts based on either static MCA or dynamic decision-making strategies. This criterion does not encompass the full domain of economic co-benefits, but shows the macroeconomic dimension.

Although several limitations have already been highlighted within the discussion, I would like to emphasise five limitations and directions for further research in particular. First, the results of this study are **constrained by the availability and resolution of CCA data**. The disaggregation across countries relies on the ETA. Although the Copernicus Institute found that northern, southern, and western Europe all rely on similar types of CCA measures, a more critical analysis can be conducted if more granular data becomes available [Copernicus Climate Change Service, 2024]. To date, **national-level** quantitative data on adaptation have been limited, making it difficult to assess and compare CCA performance across countries. As a result, a European-level pattern has been applied uniformly to each country in relation to the supplying sectors. Access to more detailed quantitative data, specifying which sectors purchase which types of CCA measures and how this varies across countries, would enable more granular and accurate insights on the importance of several sectors, the value added allocation and the DVA-returns.

This study used an MRIO framework to conduct the analysis. While this approach has certain inherent limitations, some were mitigated by narrowing the scope, timeframe, and research questions that relate to the suitability of the model. One important limitation that remains, however, is **the assumption of constant returns to scale**. More critically, the MRIO relies on fixed input structures for each of the 19 sectors. This assumes that the same input mix of the general economy is used for CCA purposes. As a result, backward linkages derived from the MRIO may **not fully capture the sector-specific nuances of adaptation-related demand**. This is mainly important regarding the manufacturing and water & waste management. Take manufacturing, for example. This input structure encompasses any product made in this sector, such as cars, vacuum cleaners, or other non-related CCA products. This input structure can therefore differ widely from the actual input structure for CCA purposes. The same accounts for water & waste management, where products can widely differ. Understanding where the actual CCA investment comes from and which products are most commonly used across hazards can help give the input matrices more granularity. This would then have a positive effect on the design of more targeted industrial policies, improve the identification of value-added generation, and lead to more precise estimates of macroeconomic returns. Besides, it would also give more insights into the discussion of supranational governance on CCA. While the findings suggest that CCA investments can generate meaningful economic spill-overs, the relatively limited extent of these effects points to a need for more granular analysis of cross-border value chain linkages. Future research should further assess the feasibility and design of equitable funding mechanisms, particularly in light of increasing regional disparities projected under climate change.

Although this study confirms that public CCA tends to follow a more public-oriented investment pattern, the interplay between public and private CCA efforts warrants further qualitative (through case studies) and quantitative investigation. This study **focused explicitly on public expenditure and did not account for fiscal instruments**—such as subsidies, tax incentives, or concessional loans—that shape CCA outcomes. These fiscal instruments are increasingly more used, especially in joint adaptation efforts. An understanding of how these tools influence private sector mobilisation is essential to assess whether the adaptation market is allocating resources efficiently. While the literature has extensively discussed market failures and barriers to private CCA, there is limited quantitative insight into how public and private actors interact, and whether the adaptation market is efficiently allocating CCA resources. In line with this, further research can be conducted to investigate the effectiveness of public CCA strategies, allowing for prioritisation of CCA strategies based on effectiveness, costs, and macroeconomic gain.

This study used a DVA-return metric to inform about the returned domestic value added of the initial investment. This metric includes the direct and indirect effects of CCA investments on the domestic macro economy. As known in literature, an investment can induce another effect, the so-called induced effect, which represents the additional consumption that occurs due to national wage increases or capital increases of the initial investment. If this third effect is included, it results in a Type II multiplier, often referred to as a closed or total multiplier. **This study does not assess the total multiplier due to limited data availability** and the need for a substantial number of additional assumptions, such as a linear-income-consumption assumption, accounting for national differences in wages and consumption patterns, modelling wage redistribution across countries, and evenly distributing EU-level consumption across all member states. Nonetheless, a more limited type of multiplier is now used, which does not entirely reflect the value added return on investments. So to this end, this study may have found underestimating DVA-returns.

Lastly, and most importantly, both the uncertainty surrounding climate impacts and the persistence of resource constraints are inevitable and will continue to be so in the future. As for this reason, further research should focus on quantifying decision-making criteria that improve decision-making under uncertainty. While several institutions and scholars have laid important groundwork—highlighting that CCA can advance multiple objectives—there remains a need for more rigorous quantification of these benefits. This study aimed to contribute by capturing macroeconomic co-benefits, **but the economic co-benefits extend well beyond this field**. Future work should quantify metrics such as productivity gains, increased local investment, or FDI linked to risk reduction. However, capturing these effects quantitatively is challenging due to data limitations, attribution difficulties, and the long time horizons over which many CCA benefits materialise. As a result, while econometric analysis or firm-level data may offer partial insights, they are unlikely to capture the full scope of these benefits. Therefore, more qualitative research, such as case studies and expert interviews, is essential to understand the broader impacts of adaptation and to complement limited quantitative evidence. These additional co-benefits can then either be merged in a comprehensive economic metric or be used together to more effectively map the economic outcomes of CCA investments. To conclude, promising decision-support frameworks such as Many-Objective-Robust Decision Making, Robust Decision Making, and adaptive pathways offer valuable tools for optimising CCA planning over time, yet their potential remains underutilised due to a lack of quantified, multi-objective inputs.

A Mathematical derivation of Equal Technology Assumption

Let:

- S be the set of **sectors** ($s = 1, \ldots, 19$).
- H be the set of **hazards** ($h = 1, \ldots, 5$).
- $T^h_{S,s'}$ denote the **transactional value** from sector S towards sector s' for hazard h.

$$T^h_S = \sum_{S \in s'} T^h_{S,s'} = \left[T^h_{S,s^1} + T^h_{S,s^2} + \cdots + T^h_{S,s^{19}} \right] \tag{A.1}$$

The transactional values are then normalized by dividing each individual supplying sector s' by the total purchase value of the sector S, through equation A.2.

$$A^h_{S,s'} = \frac{T^h_{S,s'}}{T^h_S} \tag{A.2}$$

With this you obtain for each sector and hazard a EU-distribution set A^h_S, as shown in equation A.3.

$$A^h_S = \sum_{S \in s'} A^h_{S,s'} = \left[A^h_{S,s^1} + A^h_{S,s^2} + \cdots + A^h_{S,s^{19}} \right] = 1 \tag{A.3}$$

As mentioned earlier, the Equal Technology Assumption means that each country's sector purchases follow the uniform normalized EU-wide distribution. So the EU-wide distribution is the same for each country C, see equation A.4.

$$A^{C,h}_S = A^h_S \tag{A.4}$$

Keep in mind that $A^{C,h}_S$ is a list, shown in equation A.3, with the separate coefficients on nation level for each sector s'. Now we can load Part B of the database and import the national adaptation values for each sector. If we multiply this national adaptation value against the list of nation-wide distributions we get the sectoral spending pattern on nation-level.

$$T^{C,h}_S * A^{C,h}_S = T^{C,h}_S * \sum_{S \in s'} A^{C,h}_{S,s'} = \sum_{S \in s'} T^{C,h}_{S,s'} = [\, T^{C,h}_{S,s^1} + T^{C,h}_{S,s^2} + ... + T^{C,h}_{S,s^{19}}] \tag{A.5}$$

Equation A.5 shows that now for each sector S in each country C it is known how much they purchase from the other sectors s' for each hazard h. For a non-mathematical explanation, see A

Box 1: An Example of Austria's Construction Sector

Part A of the database shows the information for each sector, in this case the construction sector, from which sectors they buy adaptation goods from:

$$\text{EU}^{\text{Flooding}}_{\text{Construction}} = 300M_{\text{Agriculture}} + 200M_{\text{Mining}} + \cdots + 500M_{\text{Manufacturing}}$$

These purchases will then be normalized through dividing the individual sectoral purchases by the total EU construction purchases:

$$[\mathrm{EU}^{\mathrm{Flooding}}_{\mathrm{Construction}}] = 0.3_{\mathrm{Agriculture}} + 0.2_{\mathrm{Mining}} + \cdots + 0.5_{\mathrm{Manufacturing}}$$

Part B of the Dataset will then be loaded, where the national purchase values per sector are represented as:

$$Austria^{Flooding}_{Construction} = 60\ M$$

The EU-wide distribution set will now be integrated into the national absolute values for each industry resulting in:

$$[Austria^{Flooding}_{Construction}] = Austria^{Flooding}_{Construction} * [\mathrm{EU}^{\mathrm{Flooding}}_{\mathrm{Construction}}]$$

$$[Austria^{Flooding}_{Construction}] = 60 * [0.3_{\mathrm{Agriculture}} + 0.2_{\mathrm{Mining}} + \cdots + 0.5_{\mathrm{Manufacturing}}]$$

$$[Austria^{Flooding}_{Construction}] = 18M_{Agriculture} + 12M_{Mining} + ... + 30M_{Manufacturing}$$

B Mathematical derivation of Trade Flow Assumption

Let:

- C be the set of **countries** ($C = 1, \ldots, 46$)
- S be the set of **sectors** ($S = 1, \ldots, 19$)
- $T^S_{C,c'}$ denote the **transactional value** from country C towards country c' for particular sector S

$$T^S_C = \sum_{C \in c'} T^S_{C,c'} = \left[T^S_{C,c^1} + T^S_{C,c^2} + \cdots + T^S_{C,c^{46}} \right] \tag{B.1}$$

The total transactional value of a certain sector S in country C is the sum of the purchases domestically plus the purchases from foreign countries. This is captured by the list T^S_C, this list will then be normalized by dividing each individual value by the total transactional value. See equation B.2.

$$A^S_{C,c'} = \frac{T^S_{C,c'}}{T^S_C} \tag{B.2}$$

We will then retrieve a trade flow coefficient list per industry for each country, which is represented in equation B.3.

$$A^S_C = \sum_{C \in c'} A^S_{C,c'} = \left[A^S_{C,c^1} + A^S_{C,c^2} + \cdots + A^S_{C,c^{46}} \right] = 1 \tag{B.3}$$

This trade flow coefficient list essentially shows how much of the share of the industry of a particular country is coming domestically and/or from foreign countries. If we multiply this list against the absolute transactional value of the industry, we will receive trade flow transactional values. See equation B.4

$$T^{S,s'}_C * A^S_C = T^{S,s'}_C * \sum_{C \in c'} A^S_{C,c'} = \sum_{C \in c'} T^{S,s'}_{C,c'} = [\ T^{S,s^1}_{C,c^1} + T^{S,s^1}_{C,c^2} + \ldots + T^{S,s^1}_{C,c^{46}}] \tag{B.4}$$

Where:

- $T^{S,s'}_C$ implies the transaction T from sector S in country C towards sector s'
- A^S_C The Trade Flow Coefficient list from a sector S in country C.
- $T^{S,s'}_{C,c'}$ implies the purchase values from sector S in country C towards sector s' in country c'.
- $\sum_{C \in C'} T^{S,s'}_{C,c'}$ implies the full list of purchases of sector S in country C towards sector s' across all countries.

See B for a non-mathematical explanation.

Box 2: An Example of Austria's Construction Sector

We currently have data on which sectors supply final adaptation goods to Austria's construction sector.

$$\text{Austria\_Construction}^{Flooding} = 18M_{Agriculture} + 12M_{Mining} + ... + 30M_{Manufacturing}$$

However, we lack information on whether these purchases are sourced domestically or foreignally. By means of the Trade Flow Assumption we assume that adaptation products don't deviate from the trade flow distribution of the general economy. We therefore import the FIGARO tables again, to see for Austria construction where they generally import their agriculture from.

$$\text{Austria\_Constr.}_{\text{Agriculture}} = 500M^{\text{Austria}}_{\text{Agriculture}} + 300M^{\text{Bulgaria}}_{\text{Agriculture}} + \cdots + 200M^{\text{Brazil}}_{\text{Agriculture}}$$

These purchases are then normalized by dividing each individual sectoral purchase by the total adaptation purchases of Austria's construction sector towards agriculture:

$$[\text{Austria\_Constr.}_{\text{Agriculture}}] = 0.5^{\text{Austria}}_{\text{Agriculture}} + 0.3^{\text{Bulgaria}}_{\text{Agriculture}} + \cdots + 0.2^{\text{Brazil}}_{\text{Agriculture}}$$

From our Adaptation Dataset (see first equation), we know:

$$\text{Austria\_Constr.}^{Flooding}_{Agriculture} = 18\ M$$

The Trade Flow Coefficients will now be integrated into the national transactional value of the construction towards agriculture resulting in:

$$[\text{Austria\_Constr.}^{Flooding}_{Agriculture}] = \text{Austria\_Constr.}^{Flooding}_{Agriculture} * [\text{Austria\_Constr.}_{Agriculture}]$$

$$[\text{Austria\_Constr.}^{Flooding}_{Agriculture}] = 18 * [0.5^{Austria}_{\text{Agriculture}} + 0.3^{Bulgaria}_{\text{Agriculture}} + \cdots + 0.2^{Brazil}_{\text{Agriculture}}]$$

$$[\text{Austria\_Constr.}^{Flooding}_{Agriculture}] = 9M^{Austria}_{\text{Agriculture}} + 5.4M^{Bulgaria}_{\text{Agriculture}} + \cdots + 3.6^{Brazil}_{\text{Agriculture}}$$

C FIGARO Table Decomposition

Sectors

"Agriculture", "Mining", "Food Products", "Beverages", "Tobacco", "Textiles", "Wearing Apparel", "Leather", "Wood", "Paper", "Printing", "Petroleum", "Chemicals", "Pharmaceuticals", "Rubber & Plastics", "Non-metallic Minerals", "Basic Metals", "Metal Products", "Electronics", "Electrical Equipment", "Machinery", "Motor Vehicles", "Other Transport", "Furniture", "Other Manufacturing", "Repair & Installation", "Electricity", "Water Supply", "Waste Management", "Construction", "Wholesale & Retail", "Land Transport", "Water Transport", "Air Transport", "Warehousing", "Accommodation & Food", "Publishing", "Film & Broadcasting", "Telecommunications", "IT Services", "Finance", "Insurance", "Real Estate", "Legal & Accounting", "Architecture & Engineering", "Scientific R&D", "Advertising", "Admin Services", "Public Administration", "Education", "Health", "Social Work", "Arts", "Gambling", "Sports", "Other Services", "Households as Employers", "Extraterritorial Organizations"

Countries

"Austria", "Belgium", "Bulgaria", "Croatia", "Cyprus", "Czechia", "Denmark", "Estonia", "Finland", "France", "Germany", "Greece", "Hungary", "Ireland", "Italy", "Latvia", "Lithuania", "Luxembourg", "Malta", "Netherlands", "Poland", "Portugal", "Romania", "Slovakia", "Slovenia", "Spain", "Sweden", "Argentina", "Australia", "Brazil", "Canada", "China", "India", "Indonesia", "Japan", "Mexico", "Norway", "Russia", "Saudi Arabia", "South Africa", "South Korea", "Switzerland", "Türkiye", "United Kingdom", "United States", "Rest of the World (RoW)"

D Mathematical derivation of the intermediate matrix and VA vector

This step retrieves coefficients of the regular *Z-matrix - and va-vector* of the FIGARO Tables and apply this on the adaptation MRIO Table. Aggregation method to align the NACE Rev. 2 codes with the kMatrix LTD is similar to the one used with the final demand matrix. With respect to, the intermediate matrix, we have accurate data on both regarding importing and exporting in the 46 regions of the world. This means the intermediate matrix has a (49 *16 =) 874 columns and (49 * 16 =) 874 rows.

$$
\begin{array}{c|c|c}
\textbf{Z-matrix} & \textbf{F-matrix} & \textbf{X-vector} \\
\begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ z_{1,j}^{1,s} & \cdots & z_{i,j}^{r,s} \end{bmatrix} &
\begin{bmatrix} f_{1,1}^{1,1} & \cdots & f_{d,1}^{r,1} \\ \vdots & \ddots & \vdots \\ f_{1,j}^{1,s} & \cdots & f_{d,j}^{r,s} \end{bmatrix} &
\begin{bmatrix} x_1^1 \\ \vdots \\ x_j^s \end{bmatrix} \\
\hline
\textbf{va-vector} & & \\
\begin{bmatrix} va_1^1 & \cdots & va_i^r \end{bmatrix} & &
\end{array}
$$

Figure D.1.: Schematic structure of the MRIO matrix

Where:

- $Z_{i,j}^{r,s}$ represents the *intermediate demand* from sector i in country r to sector j in country s.
- $f_{d,j}^{r,s}$ represents the *final demand* by actor d in country r for products from sector j in country s.
- x_j^s is the *total output* of sector i in country r.
- va_i^r is the *value added* for sector i in country r.

The column of the inter-industry transactions matrix Z represents all the inputs required by a particular sector to produce its total output. By dividing each element in a column by the total output of that sector, we obtain the *input coefficients*. The input coefficients express the amount of input from each supplying sector needed to produce one unit of output in the receiving sector. These coefficients are commonly referred to as *technical coefficients*, and they form the *technical coefficient matrix* also called the *A-matrix*.

Before we start on the computations, it is good to recall notion 1 of the MRIO: the balancing accounting identity. The total output can be computed, because of the accounting identity, through either column - or row summation. Since we have removed the final demand matrix, we are summing over the columns. Pure theoretically, by summing over the columns, we assume, that the input-distribution for one output is indifferent regarding final demand actor. This assumption arises because, while we visually remove the final demand components such as household consumption from the analysis, we do not explicitly filter out the influence of this final demand actor from the intermediate use matrix.

The technical coefficient $a_{i,j}^{r,s}$ is defined in mathematical terms in equation D.1 and in matrix terms in equation D.2:

$$a_{i,j}^{r,s} = \frac{z_{i,j}^{r,s}}{x_i^r} \qquad \text{(D.1)}$$

$$\mathbf{A} = \mathbf{Z}\,\hat{\mathbf{x}}^{-1} \qquad \text{(D.2)}$$

The coefficients $a_{ij}^{r,r}$ and $a_{ij}^{s,s}$ capture domestic input-output relationships within countries, while the coefficients $a_{ij}^{r,s}$ for $r \neq s$ reflect cross-border trade linkages between industries located in different countries.

The full expression is denoted in equation D.3.

$$\begin{bmatrix} a_{1,1}^{1,1} & \cdots & a_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ a_{1,j}^{1,s} & \cdots & a_{i,j}^{r,s} \end{bmatrix} = \begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ z_{1,j}^{1,s} & \cdots & z_{i,j}^{r,s} \end{bmatrix} * \begin{bmatrix} \frac{1}{x_1} & & \\ & \ddots & \\ & & \frac{1}{x_n} \end{bmatrix} \tag{D.3}$$

This technical coefficient matrix can also be constructed for the value added vector, you would then include the share of primary inputs needed for the total output. See equation D.14.

$$\begin{bmatrix} v_1^1 & \ldots & v_i^r \end{bmatrix} = \begin{bmatrix} va_1^1 & \ldots & va_i^r \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{x_1^1} & \cdots & \frac{1}{x_1^r} \end{bmatrix} \tag{D.4}$$

This gives us next to the **A**−matrix also the **v**−vector. Note the difference of **va**−vector and **v**-vector, where the first represent the actual values and the latter the value added coefficient. In reality, the value added is given as 5 different components, and essentially captures a small matrix. Since we most of the time aggregate it to total value added, the computations are shown in vectors.

At this point, we have constructed the technical coefficient matrix, denoted by **A**. Next, we need to construct the *Leontief inverse*. The Leontief inverse quantifies the total *direct and indirect* output requirements throughout the economy resulting from a change in final demand. The *direct effect* refers to the immediate output generated by a final demand transaction, *the indirect effect* represents the backward linkages.

The fundamental input-output relationship expressed in equation D.2 can be reformulated as D.5. From another input output relationship, we know that **Zi** can be expressed by equation 2.2. We will rewrite this equation such that **Zi** is isolated, see equation D.6

$$\mathbf{Zi} = \mathbf{Ax} \tag{D.5}$$

$$\mathbf{Zi} = \mathbf{x} - \mathbf{Fi} \tag{D.6}$$

Using the D.5 and D.6 identities , we can reformulate the system in mathematical terms as equation D.7 and in matrix terms as equation D.8 :

$$\mathbf{x} = \mathbf{Ax} + \mathbf{Fi} \tag{D.7}$$

$$\mathbf{x} = \begin{bmatrix} x_1^1 \\ \vdots \\ x_j^s \end{bmatrix} = \begin{bmatrix} a_{1,1}^{1,1} & \cdots & a_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ a_{1,j}^{1,s} & \cdots & a_{i,j}^{r,s} \end{bmatrix} \mathbf{x} + \begin{bmatrix} f_{1,1}^{1,1} & \cdots & f_{d,1}^{r,1} \\ \vdots & \ddots & \vdots \\ f_{1,j}^{1,s} & \cdots & f_{d,j}^{r,s} \end{bmatrix} \mathbf{i} \tag{D.8}$$

Finally, we have to rewrite this function, so that x gets isolated. This is done through equation D.9.

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Fi} = \mathbf{LFi} \tag{D.9}$$

So, formally, the Leontief inverse is given by:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \tag{D.10}$$

The Leontief inverse matrix is derived from the identity matrix **I** and the technical coefficient matrix **A**, as shown in equation (D.10). The **A**-matrix itself, as defined in equation (D.3), is constructed from the **Z**-matrix and the total output vector **x**, both of which are extracted from the FIGARO input-output tables. As a result, the Leontief inverse matrix we compute at this stage closely mirrors that of the general economy. This makes sense, since we introduced the trade flow assumption that an adaptation-related product follows the same trade flow pattern as a general product within the same sector. The technical coefficients and leontief inverses are based on the FIGARO tables, and are thus not modified yet to the adaptation purchases.

The *Leontief matrix* captures the total effect of an increase in final demand for a given sector d on the entire economy. If final demand in sector d increases by 1 euro, the Leontief matrix shows how much output is required not only from sector d itself (which will always be at least 1 euro), but also from all upstream sectors that supply inputs to it. If we then multiply the Leontief inverse Matrix **L** with the vector of total final demand, we would, following the logic above, obtain its total output. When we instead multiply **L** by the adaptation-specific final demand, we derive the total output attributable to the adaptation streams. Refer to equation D.11 for mathematical notation and D.12 for matrix notation.

$$\mathbf{x} = \mathbf{L} \cdot \mathbf{F} \tag{D.11}$$

$$\begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} L_{1,1}^{1,1} & \dots & L_{j,1}^{r,1} \\ \vdots & \ddots & \vdots \\ L_{1,j}^{1,s} & \dots & L_{i,j}^{r,s} \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} \tag{D.12}$$

In conclusion, we have extracted the total adaptation output $\mathbf{x}-$vector at the sector and country level and previously retrieved the final adaptation demand $\mathbf{F}-$matrix. The final step is to transform the intermediate matrix **Z**, which is currently in Leontief format, into actual adaptation-related purchases.

The final step is to convert the general-economy input coefficients into actual adaptation-related inter-industry transactions. This is done by multiplying the technical coefficient matrix **A** by the total adaptation output vector **x**. This operation scales the input shares to match the actual adaptation-related production levels in each sector. This is done through the logic of equation D.5.

This equation can be written in matrix notation as:

$$\begin{bmatrix} z_{1,1}^{1,1} & \cdots & z_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ z_{1,j}^{1,s} & \cdots & z_{i,j}^{r,s} \end{bmatrix} = \begin{bmatrix} a_{1,1}^{1,1} & \cdots & a_{i,1}^{r,1} \\ \vdots & \ddots & \vdots \\ a_{1,j}^{1,s} & \cdots & a_{i,j}^{r,s} \end{bmatrix} * \begin{bmatrix} x_1^1 \\ \vdots \\ x_j^s \end{bmatrix} \tag{D.13}$$

and for value added as:

$$\begin{bmatrix} va_1^1 & \dots & va_i^r \end{bmatrix} = \begin{bmatrix} v_1^1 & \dots & v_i^r \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{x_1^1} & \cdots & \frac{1}{x_1^r} \end{bmatrix} \tag{D.14}$$

This computation gives the transactional values of all inputs—including value added—needed to support adaptation-related production across sectors. It reveals not only the intermediate transactions between industries but also the share of adaptation output that is attributed to primary inputs such as labor and capital.

E Mathematical elaboration of deflation techniques

To compare adaptation purchases across years, we have to translate the nominal MRIOs towards real MRIOs. As explained in chapter 3, we will do this through the double deflation method. This method assumes to deflate first the input, where each individual input sector is deflated by its own deflator, and afterwards the output of the processing sector is deflated. Recall notion 1 of the MRIO, where on accounting identity can defined as equation E.1.

$$\mathbf{x} = \mathbf{Zi} + \mathbf{v} \tag{E.1}$$

If we deflate $\mathbf{x}$ and deflate $\mathbf{Z}$, we can retrieve the deflated **va**, or real value added. In MRIO technical terms this means: deflate each row in the $\mathbf{Z}-$matrix with its unique deflator. This is called *uniform row evaluation*. If we then substract the sum of the columns of the deflated $\mathbf{Z}-$matrix from the deflated $\mathbf{x}-$vector, we get the deflated $\mathbf{va}-$vector.

To perform the *uniform row valuation*, we need sectoral- and country-level deflators, which is (19 * 46 =) 874 unique deflators. These are obtained from the Asian Development Bank-databases, since they have MRIO's in current and constant prices. The deflator for sector i in country c at year t is computed as:

$$d_{i,c,t} = \frac{x_{i,c,t}^{\text{curr}}}{x_{i,c,t}^{\text{const}}} \tag{E.2}$$

where $x_{i,c,t}^{\text{curr}}$ is the total output at current prices, and $x_{i,c,t}^{\text{const}}$ is the total output at constant prices.

To ensure comparability across time, all deflators are rebased to the beginning of the Adaptation Dataset, which is 2018. This is done through:

$$d_{i,c,t} = \frac{d_{i,c,t}}{d_{i,c,2018}} \tag{E.3}$$

where $d_{i,c,t}$ is the deflator for sector i in country c at year t.

Argentina, South Africa, Saudi-Arabia, are not covered by the Asian Development Bank. We therefore extract deflators from the World Bank national accounts and similarly rebase them to 2018. After aligning the sector classification to match our own MRIO, we apply the deflators on our own $\mathbf{Z}-$matrix and $\mathbf{x}-$vector. Afterwards, according to E.1, we substract the values and obtain the real value added.

Recall notion 2 of MRIO-table, where GDP can be computed in three ways. The total GDP generation of the European adaptation streams can now easily be computed through the output computation of GDP, by summing the real value added of all industries.

F Matrix Decomposition Based on Borin & Mancini

This appendix presents the algebraic framework of the source-based decomposition methodology introduced by Borin and Mancini (2019). The exposition uses matrix algebra to express and compute forward-traced value added in exports.

Let:

- G: number of countries, N: number of sectors per country
- $A \in \mathbb{R}^{GN \times GN}$: global technical coefficients matrix, partitioned by country blocks $A_{ij} \in \mathbb{R}^{N \times N}$
- I: identity matrix
- $B = (I - A)^{-1}$: global Leontief inverse
- $\widehat{v} \in \mathbb{R}^{GN \times GN}$: a matrix of value-added coefficients, where $v_i = \frac{VA_i}{x_i}$
- $Y \in \mathbb{R}^{GN \times GF}$: final demand matrix, subdivided into bilateral blocks Y_{sr}
- $Z \in \mathbb{R}^{GN \times GN}$: intermediate demand matrix, subdivided into blocks Z_{sr}

The gross exports from country s to r are:

$$E_{sr} = Y_{sr} + Z_{sr}$$

where:

- Y_{sr}: final goods exported from s to r
- Z_{sr}: intermediate goods exported from s to r

To isolate value-added that originates in s and does not return through foreign production loops, define the truncated input matrix A^{-s}:

$$A_{ij}^{-s} = \begin{cases} A_{ij} & \text{if } j \neq s \\ 0 & \text{if } j = s \text{ and } i \neq s \end{cases}$$

This leads to the truncated Leontief inverse:

$$B^{-s} = (I - A^{-s})^{-1}$$

Let $P_s \in \mathbb{R}^{GN \times GN}$ be a binary diagonal projection matrix that selects sectors belonging to country s, i.e., $P_s x = x_s$.

Matrix Formulas for Source-Based Value Added in Exports

Domestic Value Added in Final Demand Exports:

$$DVAX_{sr}^{F} = \widehat{v}_s B_{ss}^{-s} Y_{sr}$$

Domestic Value Added in Intermediate Demand Exports:

$$DVAX_{sr}^{I} = \widehat{v}_s B_{ss}^{-s} Z_{sr}$$

Total Domestic Value Added in Exports:

$$DVAX_{sr} = DVAX^F_{sr} + DVAX^I_{sr} = \widehat{v}_s B^{-s}_{ss}(Y_{sr} + Z_{sr})$$

Foreign Value Added in Exports (from third countries $t \neq s$):

$$FVA_{sr} = \sum_{t \neq s} \widehat{v}_t B^{-s}_{ts}(Y_{sr} + Z_{sr})$$

These expressions can be vertically summed across destination countries r to produce country-level indicators.

Country-Level Aggregates

Total DVA in exports from country s:

$$DVAX_s = \sum_r \widehat{v}_s B^{-s}_{ss}(Y_{sr} + Z_{sr})$$

Share of DVA in Exports Over Total Domestic VA:

$$\text{DVA Export Share}_s = \frac{DVAX_s}{VA_s} = \frac{\mathbf{1}^T \cdot DVAX_s}{\mathbf{1}^T \cdot (\widehat{v}_s x_s)}$$

G Demand & Output figures for Other, Wildfires and drought for 2023

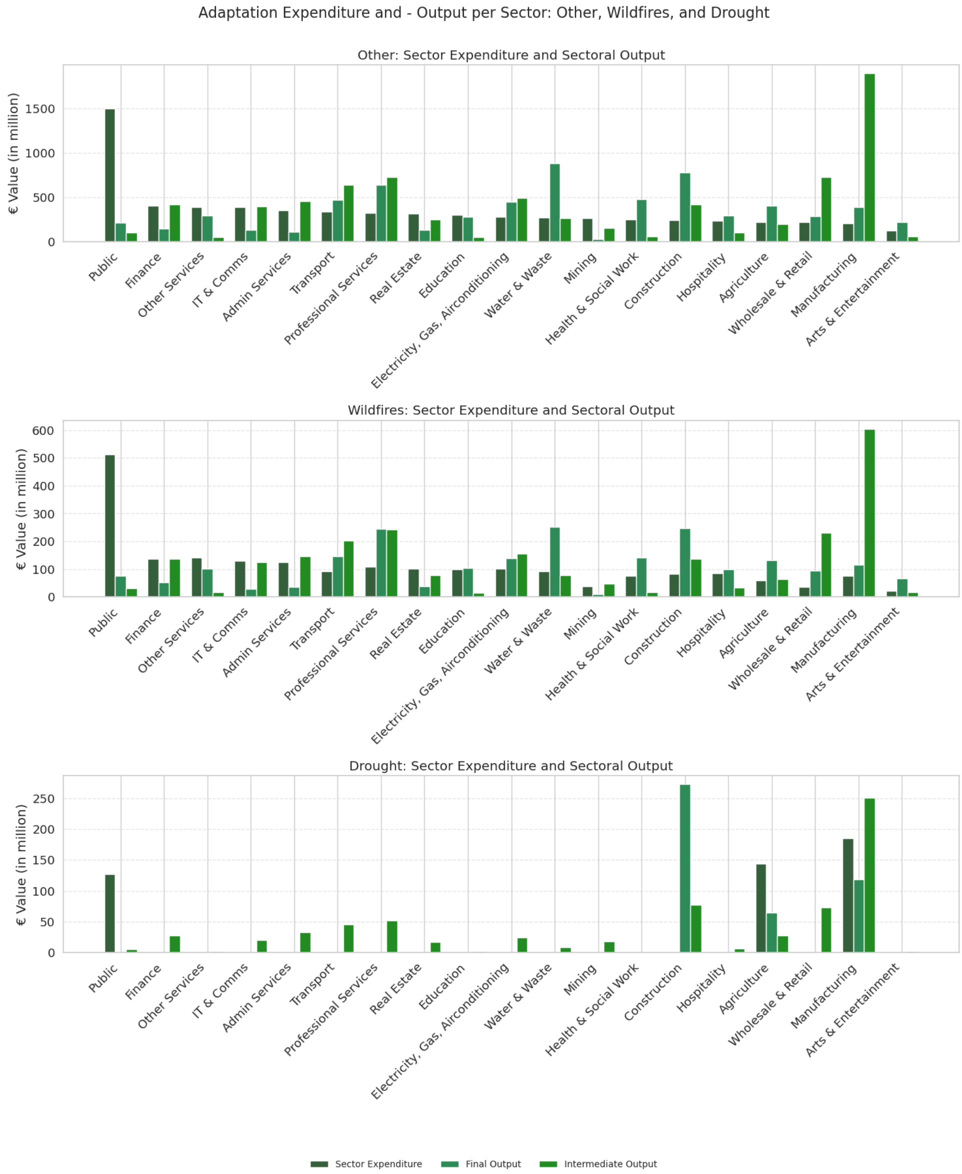

Figure G.1.: Sectoral expenditure, - final output and - intermediate output denoted in million euros. Values are shown for Other, Wildfires and Drought

H CCA relative to General Economy Table

See next page.

	AT	BE	BG	CY	CZ	DE	DK	EE
EXGR	0.00302781	0.003667003	0.003383622	0.001655623	0.002596116	0.00239881	0.002073867	0.002711926
EXGR_FNL	0.004101804	0.005964815	0.005175525	0.001521397	0.00254364	0.002919377	0.002469906	0.003024947
EXGR_INT	0.002446727	0.002682323	0.002553084	0.001715583	0.002634373	0.002081367	0.001872769	0.002571152
IMGR	0.002553034	0.00359487	0.004176772	0.002963038	0.00306996	0.004172726	0.002989439	0.003038388
IMGR_FNL	0.002195857	0.004212406	0.005104685	0.00638709	0.002477757	0.00498071	0.005866654	0.003247201
IMGR_INT	0.002708564	0.003417286	0.003574445	0.001679095	0.003274969	0.003682784	0.002173091	0.00294325
DOM	0.003814026	0.003894267	0.004245077	0.00202917	0.004599518	0.004968437	0.002441247	0.003342494
DOM_FNL	0.003495702	0.003522922	0.004349444	0.002050854	0.005010203	0.005407821	0.002367592	0.003253321
DOM_INT	0.004161549	0.004276334	0.004156656	0.002001678	0.004241919	0.004551394	0.002529824	0.003432088
BALGR	-0.01923091	-0.01670074	0.03050856	0.022065198	-0.14739498	-0.01817812	-0.00202198	0.023041403
EXGR_DVA	0.003659706	0.004250557	0.003715136	0.001900458	0.003022636	0.002587552	0.00232672	0.002990925
EXGR_DDC	0.004060302	0.004572251	0.004087941	0.002047966	0.003465925	0.002956438	0.002410081	0.003136284
EXGR_IDC	0.002868803	0.003606999	0.003204643	0.00149067	0.002365551	0.002106096	0.002156422	0.002726345
EXGR_RIM	0.001907876	0.00275059	0.002368434	0.001460865	0.001936713	0.001704829	0.00157261	0.00238555
REF	0.002287137	0.003102944	0.003040608	0.003592986	0.003222965	0.003608353	0.003260868	0.00346487
FD_VA	0.003546315	0.003679394	0.004025732	0.00196508	0.004216839	0.004552062	0.002263535	0.003021997
DXD_DVA	0.00348504	0.003339302	0.004256763	0.002003454	0.004904975	0.005373082	0.002228339	0.003042683
FFD_DVA	0.003678537	0.004270891	0.003718403	0.001899894	0.003027313	0.002566471	0.002326122	0.002991104
DFD_FVA	0.002846404	0.004130736	0.004925107	0.004514447	0.003941026	0.005259923	0.004287668	0.003555673
BALVAFD	-0.01923091	-0.01670074	0.03050856	0.022065198	-0.14739498	-0.01817812	-0.00202198	0.023041403
EXGR_FVA	0.002135786	0.002991647	0.002792036	0.001447138	0.002121169	0.001901669	0.001706914	0.002348915
DEXFVAP	0.002135786	0.002991647	0.002792036	0.001447138	0.002121169	0.001901669	0.001706914	0.002348915
FEXDVAP	0.001703095	0.001712156	0.00173953	0.001647113	0.001828405	0.001641852	0.001639129	0.001922445
VA	0.003546315	0.003679394	0.004025732	0.00196508	0.004216839	0.004552062	0.002263535	0.003021997
PROD	0.003614801	0.003827785	0.003993645	0.001896665	0.004027154	0.004451581	0.002330753	0.003145459
SPENDING	0.011578451	0.014739158	0.024717505	0.014785811	0.01572999	0.022208974	0.010838211	0.010923132

	ES	GB	GR	HR	HU	IE	IT	LT	LU
EXGR	0.002936911	0.002563785	0.00188215	0.004608224	0.002658561	0.001508606	0.00195489	0.002974156	0.002441808
EXGR_FNL	0.004200486	0.004233951	0.00235206	0.008341205	0.00300957	0.001110592	0.002011067	0.004054063	0.001053827
EXGR_INT	0.002191043	0.001781686	0.001673264	0.002673987	0.002409053	0.001824654	0.001914457	0.00251955	0.002903427
IMGR	0.0038931	0.003075683	0.005263797	0.004131175	0.002953184	0.002133541	0.003866286	0.003355525	0.002749287
IMGR_FNL	0.004176671	0.002996382	0.006425468	0.003300399	0.003149595	0.003668792	0.004970922	0.003337328	0.005514806
IMGR_INT	0.003766854	0.003145033	0.004352328	0.004858842	0.002890368	0.001448276	0.003386552	0.003366412	0.002444276
DOM	0.00456122	0.003299243	0.006615281	0.005191116	0.004117982	0.001509581	0.005298937	0.004007683	0.002416627
DOM_FNL	0.004599212	0.003226525	0.006918599	0.005170672	0.004264516	0.001188378	0.005418184	0.00431087	0.002424092
DOM_INT	0.004519199	0.003390141	0.006125105	0.00522054	0.003937128	0.001850072	0.005186818	0.003678392	0.002414075
BALGR	0.021771686	0.009738146	0.012618167	0.003672728	0.006808073	0.000219631	0.025730768	0.015825338	0.001132733
EXGR_DVA	0.003293874	0.00271986	0.002327882	0.004873448	0.0033631	0.001566766	0.002216811	0.003204448	0.002615269
EXGR_DDC	0.0038871	0.003004225	0.002566769	0.005298586	0.003649651	0.001561419	0.002673083	0.003489358	0.003249592
EXGR_IDC	0.002535542	0.002136043	0.001906621	0.004135336	0.002778913	0.001621564	0.001754833	0.002598192	0.00168346
EXGR_RIM	0.002027992	0.00188183	0.001164708	0.00341735	0.002105527	0.001170177	0.001421527	0.002794465	0.002626577
REF	0.003489266	0.002546106	0.006771813	0.003625195	0.003014597	0.002278668	0.003910029	0.003439917	0.003403152
FD_VA	0.004198445	0.003050912	0.005709383	0.005111979	0.003827369	0.001440824	0.004718627	0.00381092	0.002429109
DXD_DVA	0.004500066	0.003144402	0.006749505	0.005166972	0.004103826	0.001078532	0.005452207	0.004240763	0.002129426
FFD_DVA	0.003298704	0.002724975	0.002316143	0.004878573	0.003369702	0.001566651	0.002200987	0.003204396	0.002614583
DFD_FVA	0.004680982	0.003352553	0.006916534	0.004167992	0.003901213	0.003263688	0.005107738	0.003812935	0.004193535
BALVAFD	0.021771686	0.009738146	0.012618167	0.003672728	0.006808073	0.000219631	0.025730768	0.015825338	0.001132733
EXGR_FVA	0.00220958	0.001957928	0.001285002	0.003897741	0.002145796	0.001424908	0.001505055	0.002618863	0.00233986
DEXFVAP	0.00220958	0.001957928	0.001285002	0.003897741	0.002145796	0.001424908	0.001505055	0.002618863	0.00233986
FEXDVAP	0.001649473	0.001647846	0.001550135	0.001839991	0.001754492	0.001472838	0.001624493	0.001857436	0.001930144
VA	0.004198445	0.003050912	0.005709383	0.005111979	0.003827369	0.001440824	0.004718627	0.00381092	0.002429109
PROD	0.004265838	0.003186911	0.005594661	0.005114369	0.003572498	0.001508929	0.004757254	0.003675736	0.002427668
SPENDING	0.021720344	0.020334367	0.05211008	0.027593383	0.013704893	0.005993929	0.024003219	0.018877035	0.01792981

	LV	MT	NL	PL	PT	RO	SE	SI	SK
EXGR	0.002683469	0.003341051	0.002858213	0.002865374	0.002650314	0.002989331	0.002361633	0.002996501	0.002249264
EXGR_FNL	0.003537146	0.004026964	0.004567254	0.003132724	0.00318117	0.003844128	0.003066895	0.00421248	0.002107655
EXGR_INT	0.002396716	0.00287998	0.002081809	0.002709273	0.00232385	0.002527913	0.00201339	0.002379079	0.002351963
IMGR	0.00295789	0.003179244	0.00942188	0.00294189	0.003913719	0.005963369	0.003380151	0.003539682	0.002776012
IMGR_FNL	0.002118155	0.002707346	0.016202834	0.00287163	0.004615993	0.010460194	0.004411703	0.002711015	0.002882758
IMGR_INT	0.003621057	0.003249607	0.00760395	0.002980074	0.003607647	0.002856789	0.00290123	0.003919435	0.002737703
DOM	0.003987923	0.003191074	0.011847739	0.003707261	0.004977872	0.002931464	0.003476584	0.004992486	0.004386765
DOM_FNL	0.004082657	0.002736268	0.013732812	0.00399688	0.004744421	0.002828516	0.003472214	0.005210959	0.004840625
DOM_INT	0.003885927	0.003657586	0.009906727	0.003480211	0.005254711	0.003044052	0.003481846	0.004760044	0.004008013
BALGR	0.005586403	0.006815138	-0.02682113	-0.0002908	0.009435003	0.025624802	-0.01090242	0.087972254	0.012663087
EXGR_DVA	0.002761602	0.003611791	0.003294972	0.003162771	0.003226027	0.003164447	0.002588921	0.003321366	0.002827144
EXGR_DDC	0.002892542	0.003643864	0.003596423	0.003667034	0.003580134	0.003459604	0.002838597	0.003616017	0.00336094
EXGR_IDC	0.002474113	0.003523969	0.002743503	0.002515284	0.002647257	0.002741611	0.002151117	0.00276233	0.002062262
EXGR_RIM	0.002616856	0.003252517	0.002029793	0.002127847	0.001744973	0.002506887	0.00185759	0.002136502	0.001404233
REF	0.002358924	0.00237297	0.013972185	0.0027936	0.004292235	0.004195806	0.003235979	0.003327429	0.002540878
FD_VA	0.003501142	0.003013001	0.009278843	0.003710167	0.004256483	0.002884174	0.003133009	0.004258194	0.00396477
DXD_DVA	0.003908338	0.002401495	0.012984376	0.004035755	0.004577993	0.002774954	0.003366375	0.004883379	0.004672048
FFD_DVA	0.002763318	0.003612264	0.003219575	0.003170998	0.003225756	0.003160354	0.002586966	0.003322895	0.002836793
DFD_FVA	0.003138358	0.00310364	0.016547185	0.003303673	0.005058676	0.007056856	0.004219234	0.004290522	0.003935936
BALVAFD	0.005586403	0.006815138	-0.02682113	-0.0002908	0.009435003	0.025624802	-0.01090242	0.087972254	0.012663087
EXGR_FVA	0.002513542	0.003210692	0.002206606	0.002313934	0.001944652	0.002526357	0.001901904	0.002586448	0.001818238
DEXFVAP	0.002513542	0.003210692	0.002206606	0.002313934	0.001944652	0.002526357	0.001901904	0.002586448	0.001818238
FEXDVAP	0.001908474	0.001786973	0.001727076	0.001804008	0.001761873	0.001800969	0.001653147	0.001723148	0.001695679
VA	0.003501142	0.003013001	0.009278843	0.003710167	0.004256483	0.002884174	0.003133009	0.004258194	0.00396477
PROD	0.003658311	0.003268498	0.009174577	0.003498849	0.004509538	0.002942469	0.003221402	0.004347137	0.003654383
SPENDING	0.015983644	0.009566154	0.059626336	0.020310062	0.022604681	0.017269015	0.012340309	0.03712674	0.020730865

Figure H.1.: CCA relative to General Economy Table

I Value Added in Exports 2023

This analysis goes beyond national or sectoral value-added allocation, a closer examination of the GVC allows us to investigate the cross-border linkages embedded within adaptation-related exports. See for this Figure I.1. The figure reveals the decomposition of exports by the share of intermediate vs final products and the share of DVA embedded in exports vs FVA embedded in exports. The latter introduces insights into how much of a country's export value truly originates domestically versus how much reflects imported inputs. For the exact division of DVA and FVA in exports, refer to Appendix J. Lastly, the same figure represents the share of export-induced value added as part of the total value added generated by the country. Note the difference in small-open EU member states compared to the larger EU member states

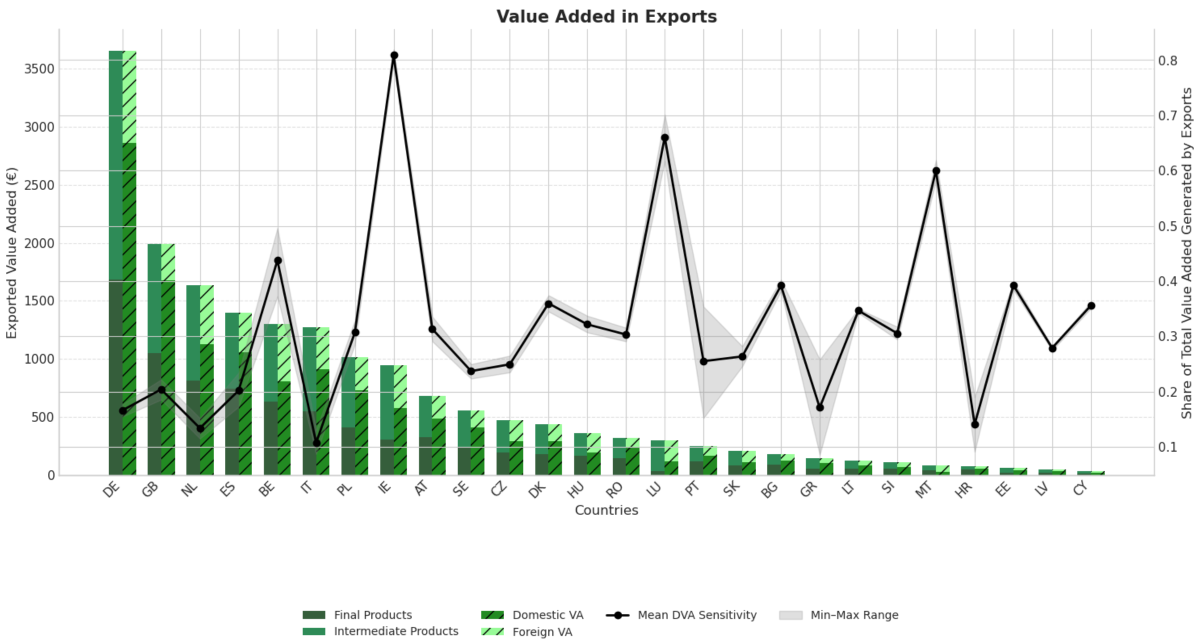

Figure I.1.: Value Added in Exports denoted in million euros. The bar charts are disaggregated by final, intermediate, domestic, and foreign value added. The line represents the FVA share of total value added.

J Global Value Chain Metrics 2023

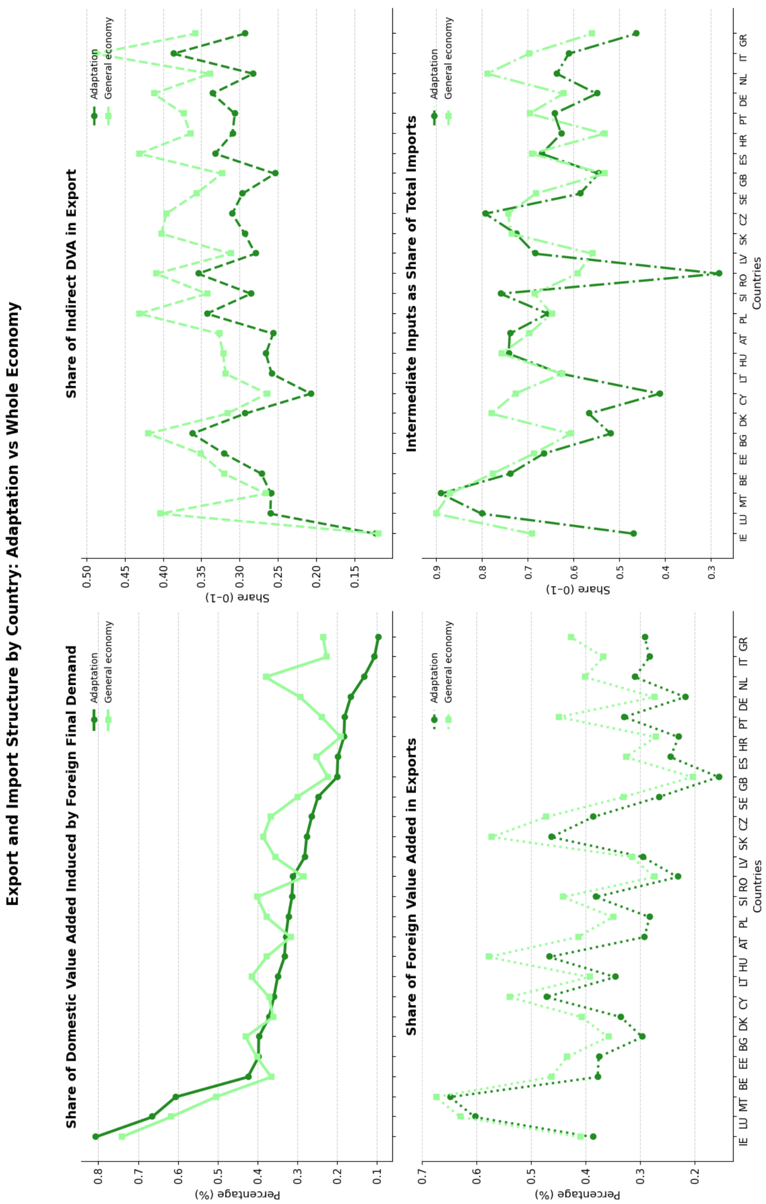

Figure J.1.: Value Added in Exports

K Case Study of Slovenia

The LIFE4ADAPT project has been co-funded by the European Commission and the Government of Slovenia. Although the absolute value of the fund does not impact the percentage-wise impact on neighbouring countries, in this study only the EU-funded part is used, which accounts for €14,177,980. Figure K.1, maps the value added distribution across Europe.

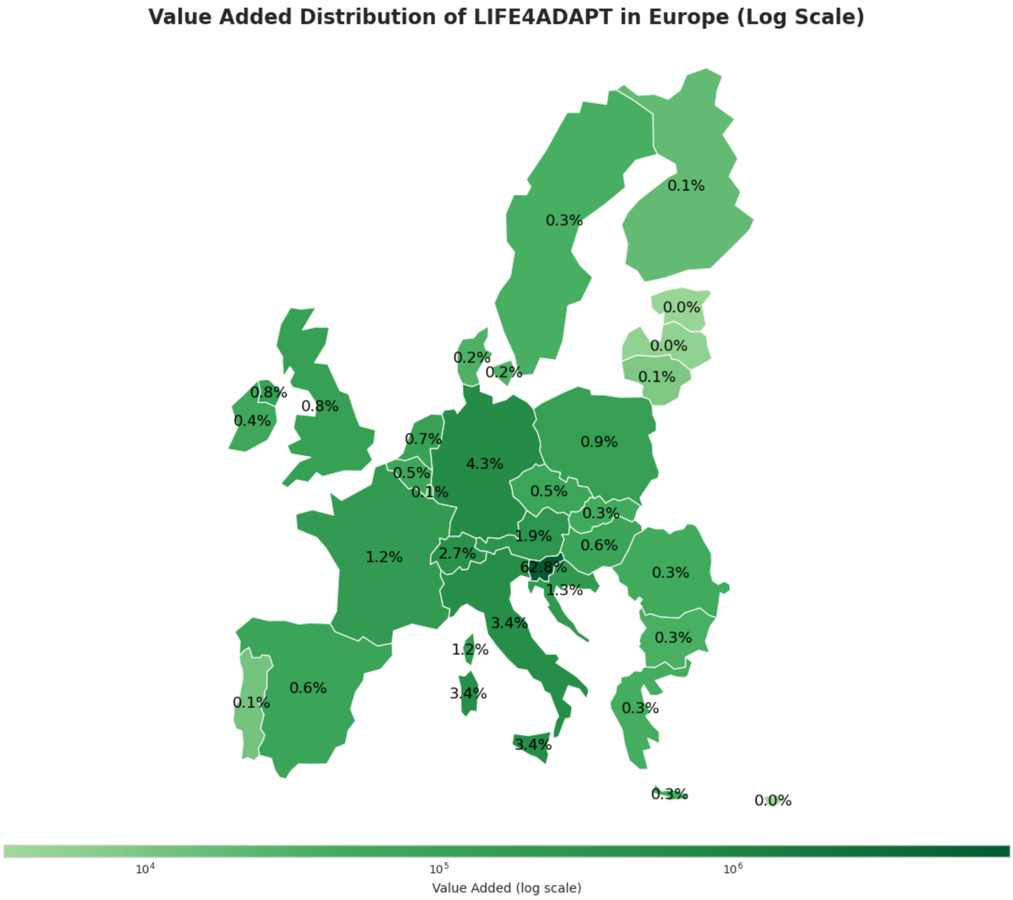

Figure K.1.: Value added distributed across Europe induced by LIFE4ADAPT in percentages

If we look at a broader scale and include non-European countries, we see that the value added is also largely distributed to non-European countries, see Table K.2. Around 37% of the European fund leaks out of Slovenia. Most of the leaking flows towards Rest of World (5.5%), Germany (4.3%), China (3.6%), Italy (3.4%) and Switzerland (2.7%).

Country	Value Added	% of EU Fund
SI	8,771,672	62.8%
RoW	761,833	5.5%
DE	600,348	4.3%
CN	507,242	3.6%
IT	478,323	3.4%
CH	382,650	2.7%
AT	270,287	1.9%
HR	186,036	1.3%
US	176,106	1.3%
FR	170,226	1.2%
RU	139,641	1.0%
PL	121,619	0.9%
GB	116,740	0.8%
NL	101,880	0.7%
ES	83,043	0.6%
HU	80,036	0.6%
CZ	75,893	0.5%
IN	75,639	0.5%
BE	67,274	0.5%
JP	66,600	0.5%

Figure K.2.: Value added distributed worldwide induced by the EU-share of the LIFE4ADAPT fund: *€14,177,980*

L Domestic Value Added Intensity with Sensitivity 2023

This appendix presents the DVA intensities with the GSA performed for the year 2023.

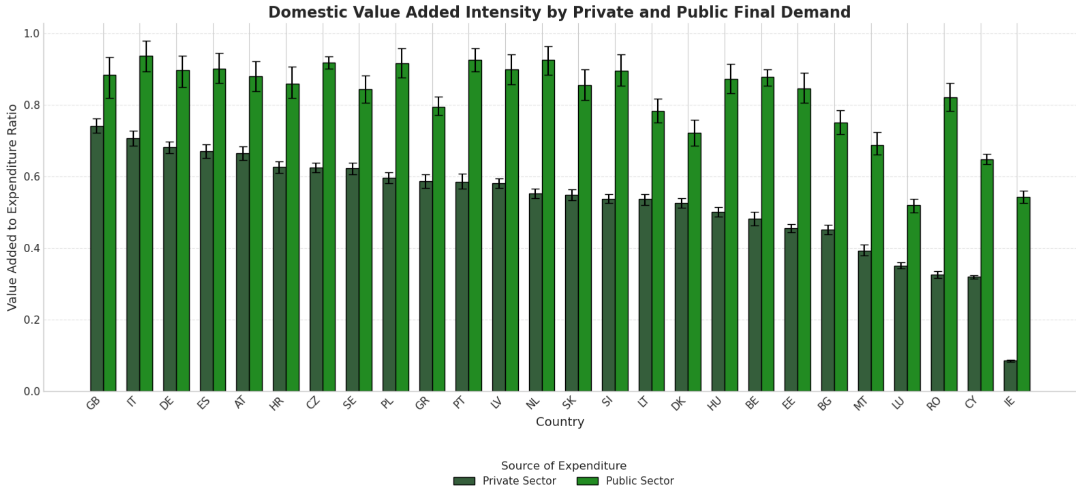

Figure L.1.: Domestic Value Added Intensity with sensitivity for public and private sector as ratios

M Macroeconomic return per hazard fully disaggregated

Country	Agri	Mining	Manuf	Energy	Water	Constr	Retail	Transp	Hospit	ITCom	Financ	Estate	ProfSv	AdminS	Public	Educat	Health	Art	OthSrv
AT	0.738	0.770	0.690	0.687	0.693	0.669	0.640	0.702	0.696	0.713	0.711	0.715	0.716	0.712	0.768	0.720	0.701	0.788	0.708
BE	0.625	0.668	0.551	0.548	0.548	0.537	0.506	0.564	0.551	0.577	0.571	0.583	0.580	0.577	0.704	0.585	0.554	0.656	0.568
BG	0.476	0.515	0.530	0.526	0.517	0.500	0.433	0.534	0.524	0.483	0.492	0.476	0.474	0.483	0.598	0.494	0.526	0.481	0.489
CZ	0.713	0.742	0.662	0.669	0.667	0.642	0.645	0.668	0.670	0.681	0.675	0.685	0.683	0.680	0.729	0.686	0.670	0.780	0.677
DK	0.621	0.622	0.552	0.558	0.560	0.547	0.546	0.522	0.556	0.589	0.570	0.574	0.600	0.577	0.577	0.587	0.555	0.708	0.585
DE	0.757	0.777	0.698	0.709	0.710	0.688	0.618	0.694	0.703	0.704	0.699	0.735	0.713	0.704	0.802	0.719	0.719	0.745	0.707
EE	0.521	0.602	0.548	0.506	0.515	0.541	0.490	0.539	0.507	0.514	0.509	0.511	0.517	0.511	0.661	0.514	0.523	0.610	0.505
IE	0.066	0.112	0.063	0.098	0.088	0.109	0.007	0.085	0.128	0.099	0.090	0.118	0.100	0.098	0.508	0.096	0.081	0.057	0.091
GR	0.657	0.687	0.630	0.619	0.625	0.617	0.581	0.610	0.618	0.631	0.626	0.620	0.636	0.620	0.646	0.635	0.632	0.683	0.628
ES	0.763	0.789	0.709	0.702	0.703	0.692	0.682	0.693	0.708	0.708	0.702	0.727	0.713	0.709	0.774	0.720	0.703	0.785	0.707
HR	0.684	0.732	0.671	0.651	0.657	0.657	0.664	0.676	0.663	0.654	0.652	0.668	0.657	0.657	0.676	0.660	0.659	0.783	0.650
IT	0.776	0.809	0.730	0.735	0.729	0.702	0.672	0.742	0.732	0.757	0.760	0.738	0.757	0.756	0.833	0.767	0.736	0.758	0.756
CY	0.379	0.397	0.341	0.370	0.370	0.348	0.343	0.302	0.332	0.354	0.318	0.375	0.361	0.346	0.524	0.348	0.356	0.364	0.346
LV	0.649	0.691	0.637	0.630	0.628	0.618	0.550	0.631	0.617	0.660	0.655	0.643	0.658	0.653	0.716	0.657	0.638	0.621	0.650
LT	0.570	0.616	0.564	0.575	0.582	0.557	0.553	0.571	0.604	0.593	0.584	0.599	0.590	0.591	0.618	0.590	0.580	0.710	0.586
LU	0.448	0.526	0.460	0.398	0.405	0.478	0.327	0.453	0.427	0.429	0.433	0.439	0.424	0.436	0.437	0.438	0.407	0.364	0.411
HU	0.584	0.647	0.579	0.543	0.553	0.566	0.529	0.563	0.551	0.553	0.547	0.572	0.558	0.554	0.670	0.561	0.557	0.670	0.547
MT	0.559	0.608	0.499	0.494	0.489	0.484	0.484	0.500	0.485	0.511	0.503	0.512	0.516	0.510	0.576	0.515	0.496	0.625	0.504
NL	0.652	0.668	0.609	0.621	0.627	0.612	0.521	0.599	0.619	0.641	0.634	0.654	0.652	0.638	0.748	0.646	0.633	0.629	0.638
PL	0.680	0.712	0.654	0.640	0.644	0.631	0.617	0.660	0.634	0.643	0.641	0.653	0.647	0.643	0.774	0.651	0.653	0.706	0.640
PT	0.674	0.715	0.647	0.647	0.656	0.633	0.604	0.647	0.660	0.670	0.663	0.676	0.674	0.665	0.748	0.673	0.661	0.761	0.665
RO	0.311	0.391	0.443	0.363	0.360	0.450	0.456	0.364	0.309	0.341	0.325	0.243	0.330	0.332	0.712	0.314	0.343	0.311	0.325
SI	0.615	0.646	0.598	0.600	0.601	0.589	0.572	0.590	0.611	0.603	0.595	0.611	0.605	0.600	0.698	0.605	0.601	0.674	0.599
SK	0.637	0.681	0.622	0.617	0.616	0.601	0.576	0.639	0.626	0.598	0.597	0.632	0.599	0.606	0.695	0.611	0.619	0.693	0.595
SE	0.669	0.698	0.661	0.660	0.657	0.650	0.576	0.650	0.649	0.667	0.665	0.658	0.671	0.665	0.720	0.672	0.661	0.639	0.665
GB	0.778	0.806	0.716	0.744	0.739	0.714	0.623	0.720	0.738	0.756	0.749	0.766	0.762	0.755	0.798	0.764	0.746	0.794	0.753

Figure M.1.: Macroeconomic return on heatwave CCA

Country	Agri	Mining	Manuf	Energy	Water	Constr	Retail	Transp	Hospit	ITCom	Financ	Estate	ProfSv	AdminS	Public	Educat	Health	Art	OthSrv
AT	0.702	0.716	0.680	0.690	0.692	0.678	0.678	0.689	0.707	0.711	0.713	0.712	0.717	0.716	0.764	0.714	0.696	0.790	0.712
BE	0.582	0.590	0.550	0.551	0.547	0.547	0.535	0.549	0.566	0.570	0.581	0.578	0.576	0.581	0.703	0.575	0.551	0.654	0.576
BG	0.433	0.319	0.519	0.532	0.519	0.510	0.432	0.548	0.546	0.476	0.479	0.478	0.485	0.482	0.604	0.478	0.519	0.490	0.482
CZ	0.694	0.703	0.655	0.673	0.666	0.652	0.683	0.663	0.679	0.675	0.680	0.683	0.680	0.684	0.727	0.681	0.666	0.775	0.682
DK	0.594	0.554	0.555	0.558	0.563	0.555	0.564	0.537	0.556	0.575	0.588	0.569	0.582	0.593	0.586	0.586	0.556	0.713	0.584
DE	0.730	0.653	0.698	0.709	0.710	0.693	0.621	0.707	0.718	0.700	0.715	0.731	0.708	0.714	0.799	0.712	0.715	0.750	0.708
EE	0.509	0.509	0.547	0.511	0.517	0.548	0.520	0.552	0.523	0.506	0.517	0.509	0.511	0.524	0.658	0.509	0.516	0.607	0.522
IE	0.094	0.007	0.097	0.084	0.082	0.107	0.006	0.095	0.137	0.083	0.103	0.120	0.087	0.103	0.497	0.087	0.083	0.076	0.103
GR	0.651	0.609	0.624	0.624	0.629	0.627	0.623	0.617	0.628	0.636	0.629	0.623	0.633	0.633	0.636	0.635	0.632	0.655	0.636
ES	0.743	0.741	0.704	0.707	0.701	0.701	0.710	0.698	0.720	0.704	0.713	0.725	0.712	0.714	0.773	0.713	0.704	0.774	0.712
HR	0.669	0.731	0.664	0.657	0.655	0.665	0.708	0.667	0.670	0.649	0.656	0.666	0.653	0.661	0.673	0.655	0.655	0.782	0.660
IT	0.731	0.699	0.721	0.739	0.733	0.716	0.680	0.740	0.748	0.757	0.759	0.736	0.759	0.760	0.831	0.753	0.733	0.780	0.754
CY	0.426	0.312	0.358	0.371	0.365	0.345	0.356	0.338	0.335	0.342	0.356	0.379	0.332	0.359	0.521	0.353	0.358	0.336	0.361
LV	0.610	0.590	0.628	0.634	0.629	0.618	0.586	0.636	0.628	0.654	0.657	0.640	0.662	0.660	0.712	0.655	0.629	0.596	0.659
LT	0.606	0.571	0.564	0.582	0.575	0.562	0.591	0.583	0.618	0.578	0.584	0.599	0.595	0.594	0.613	0.585	0.573	0.698	0.591
LU	0.372	0.454	0.468	0.396	0.398	0.473	0.378	0.431	0.441	0.422	0.434	0.430	0.439	0.431	0.434	0.426	0.413	0.343	0.432
HU	0.561	0.588	0.574	0.549	0.549	0.571	0.567	0.573	0.565	0.544	0.558	0.566	0.556	0.564	0.668	0.556	0.551	0.661	0.560
MT	0.551	0.562	0.496	0.500	0.490	0.495	0.523	0.500	0.500	0.506	0.515	0.512	0.509	0.520	0.577	0.510	0.490	0.603	0.518
NL	0.647	0.590	0.613	0.618	0.627	0.611	0.562	0.612	0.627	0.640	0.645	0.657	0.647	0.646	0.747	0.645	0.634	0.631	0.645
PL	0.651	0.651	0.646	0.645	0.645	0.640	0.650	0.646	0.646	0.644	0.645	0.653	0.643	0.645	0.772	0.646	0.651	0.696	0.647
PT	0.671	0.650	0.642	0.652	0.653	0.640	0.645	0.655	0.672	0.664	0.668	0.674	0.672	0.674	0.745	0.670	0.655	0.758	0.671
RO	0.331	0.329	0.450	0.374	0.373	0.454	0.469	0.405	0.309	0.330	0.327	0.259	0.319	0.337	0.707	0.313	0.351	0.278	0.349
SI	0.615	0.602	0.596	0.603	0.599	0.595	0.613	0.596	0.619	0.595	0.600	0.611	0.603	0.605	0.697	0.602	0.598	0.661	0.606
SK	0.595	0.636	0.614	0.620	0.612	0.608	0.632	0.618	0.636	0.590	0.601	0.630	0.597	0.603	0.693	0.603	0.615	0.696	0.605
SE	0.635	0.589	0.659	0.659	0.661	0.654	0.595	0.665	0.659	0.662	0.670	0.658	0.668	0.672	0.716	0.664	0.659	0.659	0.669
GB	0.766	0.686	0.721	0.740	0.735	0.719	0.654	0.736	0.756	0.748	0.760	0.767	0.760	0.762	0.794	0.755	0.742	0.803	0.757

Figure M.2.: Macroeconomic return on wildfire CCA

Country	Agri	Mining	Manuf	Energy	Water	Constr	Retail	Transp	Hospit	ITCom	Financ	Estate	ProfSv	AdminS	Public	Educat	Health	Art	OthSrv
AT	0.595		0.586												0.571				
BE	0.562		0.502												0.617				
BG	0.483		0.516												0.526				
CZ	0.577		0.585												0.586				
DK	0.554		0.580												0.572				
DE	0.695		0.714												0.662				
EE	0.506		0.557												0.521				
IE	0.401		0.335												0.428				
GR	0.515		0.572												0.368				
ES	0.653		0.664												0.624				
HR	0.573		0.584												0.525				
IT	0.705		0.684												0.712				
CY	0.526		0.561												0.342				
LV	0.540		0.598												0.562				
LT	0.507		0.560												0.524				
LU	0.487		0.438												0.258				
HU	0.474		0.534												0.513				
MT	0.457		0.462												0.571				
NL	0.553		0.619												0.647				
PL	0.601		0.570												0.627				
PT	0.542		0.598												0.576				
RO	0.543		0.621												0.637				
SI	0.527		0.572												0.570				
SK	0.544		0.522												0.545				
SE	0.629		0.677												0.355				
GB	0.693		0.745												0.330				

Figure M.3.: Macroeconomic return on Drought CCA

Country	Agri	Mining	Manuf	Energy	Water	Constr	Retail	Transp	Hospit	ITCom	Financ	Estate	ProfSv	AdminS	Public	Educat	Health	Art	OthSrv
AT	0.715	0.684	0.671	0.697	0.698	0.686	0.689	0.690	0.691	0.708	0.713	0.703	0.712	0.716	0.762	0.709	0.699	0.716	0.709
BE	0.591	0.565	0.536	0.554	0.551	0.550	0.568	0.548	0.549	0.567	0.576	0.576	0.574	0.577	0.700	0.571	0.557	0.565	0.571
BG	0.494	0.464	0.514	0.523	0.532	0.540	0.514	0.527	0.527	0.486	0.484	0.477	0.482	0.487	0.601	0.475	0.533	0.383	0.482
CZ	0.695	0.653	0.644	0.677	0.670	0.652	0.663	0.666	0.668	0.677	0.682	0.676	0.677	0.681	0.725	0.677	0.667	0.690	0.677
DK	0.590	0.546	0.547	0.565	0.550	0.566	0.552	0.554	0.562	0.576	0.586	0.568	0.580	0.584	0.580	0.585	0.561	0.601	0.579
DE	0.750	0.704	0.693	0.716	0.715	0.711	0.694	0.709	0.707	0.707	0.710	0.724	0.706	0.709	0.796	0.704	0.714	0.677	0.706
EE	0.526	0.533	0.534	0.507	0.527	0.562	0.512	0.500	0.510	0.507	0.506	0.510	0.500	0.516	0.657	0.505	0.528	0.454	0.500
IE	0.091	0.094	0.082	0.084	0.092	0.120	0.099	0.089	0.140	0.085	0.103	0.130	0.090	0.098	0.502	0.091	0.098	0.044	0.086
GR	0.644	0.607	0.611	0.626	0.630	0.636	0.563	0.612	0.621	0.629	0.626	0.615	0.629	0.636	0.637	0.629	0.629	0.567	0.624
ES	0.735	0.706	0.697	0.708	0.703	0.708	0.698	0.701	0.708	0.709	0.713	0.723	0.708	0.710	0.770	0.706	0.707	0.705	0.709
HR	0.668	0.663	0.655	0.656	0.661	0.666	0.666	0.650	0.658	0.654	0.657	0.663	0.646	0.654	0.671	0.651	0.662	0.688	0.651
IT	0.759	0.724	0.718	0.735	0.740	0.727	0.727	0.740	0.732	0.757	0.756	0.736	0.763	0.759	0.829	0.752	0.739	0.694	0.754
CY	0.384	0.345	0.345	0.371	0.359	0.313	0.348	0.351	0.360	0.338	0.349	0.388	0.347	0.341	0.511	0.353	0.339	0.324	0.349
LV	0.652	0.628	0.611	0.637	0.634	0.640	0.608	0.623	0.621	0.647	0.650	0.639	0.657	0.660	0.712	0.654	0.635	0.568	0.648
LT	0.583	0.542	0.552	0.582	0.585	0.570	0.584	0.567	0.605	0.582	0.587	0.588	0.587	0.592	0.613	0.580	0.580	0.583	0.587
LU	0.420	0.492	0.449	0.392	0.405	0.497	0.444	0.402	0.420	0.416	0.424	0.448	0.423	0.435	0.430	0.426	0.432	0.350	0.416
HU	0.577	0.571	0.563	0.551	0.557	0.586	0.561	0.540	0.549	0.550	0.551	0.565	0.545	0.554	0.665	0.550	0.561	0.521	0.545
MT	0.540	0.503	0.480	0.500	0.498	0.494	0.478	0.484	0.487	0.505	0.510	0.506	0.504	0.515	0.571	0.503	0.494	0.491	0.504
NL	0.655	0.615	0.606	0.628	0.632	0.628	0.566	0.619	0.621	0.639	0.644	0.647	0.641	0.652	0.745	0.642	0.625	0.603	0.633
PL	0.656	0.637	0.638	0.648	0.652	0.642	0.635	0.640	0.632	0.639	0.646	0.649	0.641	0.647	0.770	0.640	0.651	0.630	0.639
PT	0.675	0.632	0.632	0.657	0.661	0.654	0.635	0.644	0.659	0.664	0.666	0.664	0.667	0.672	0.741	0.665	0.658	0.638	0.662
RO	0.312	0.399	0.435	0.337	0.360	0.417	0.348	0.343	0.338	0.323	0.314	0.289	0.311	0.334	0.710	0.325	0.353	0.265	0.324
SI	0.609	0.580	0.583	0.605	0.603	0.604	0.581	0.593	0.612	0.598	0.604	0.606	0.596	0.604	0.695	0.598	0.603	0.600	0.598
SK	0.618	0.604	0.600	0.622	0.621	0.613	0.632	0.617	0.621	0.598	0.610	0.629	0.592	0.598	0.691	0.599	0.622	0.637	0.597
SE	0.673	0.653	0.654	0.659	0.664	0.671	0.633	0.661	0.653	0.666	0.667	0.660	0.665	0.671	0.713	0.666	0.661	0.608	0.660
GB	0.784	0.720	0.711	0.750	0.748	0.732	0.704	0.741	0.741	0.752	0.757	0.755	0.755	0.766	0.794	0.751	0.737	0.702	0.749

Figure M.4.: Macroeconomic return on Other CCA

N Graphs for the Year 2022

This appendix presents the key graphical results for 2022.

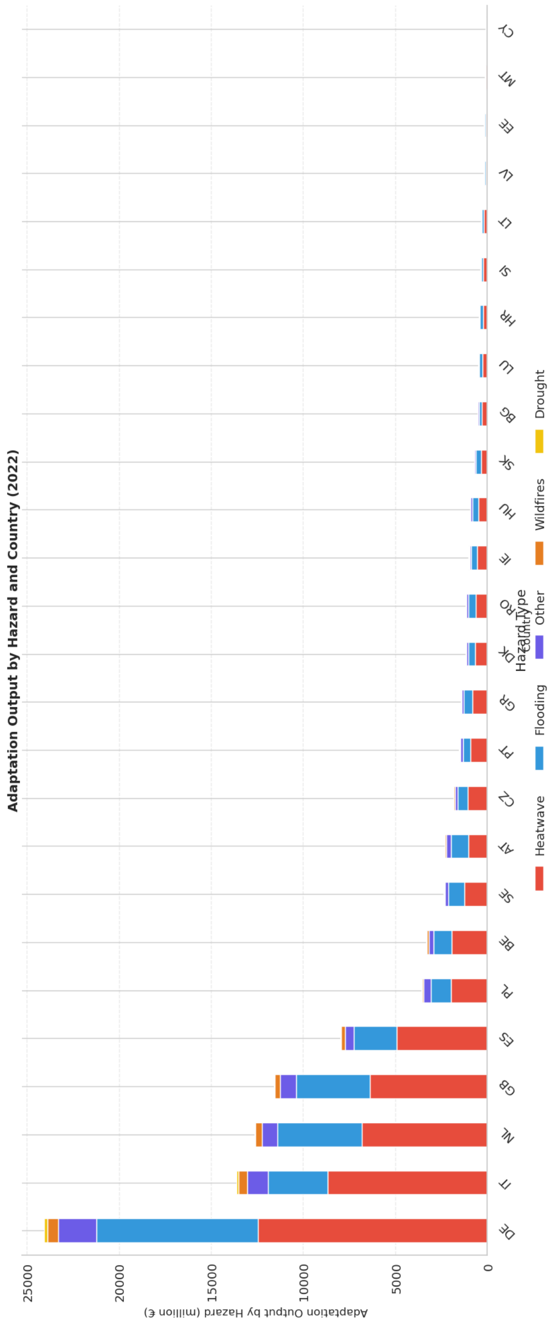

Figure N.1.: Output 2022 per country

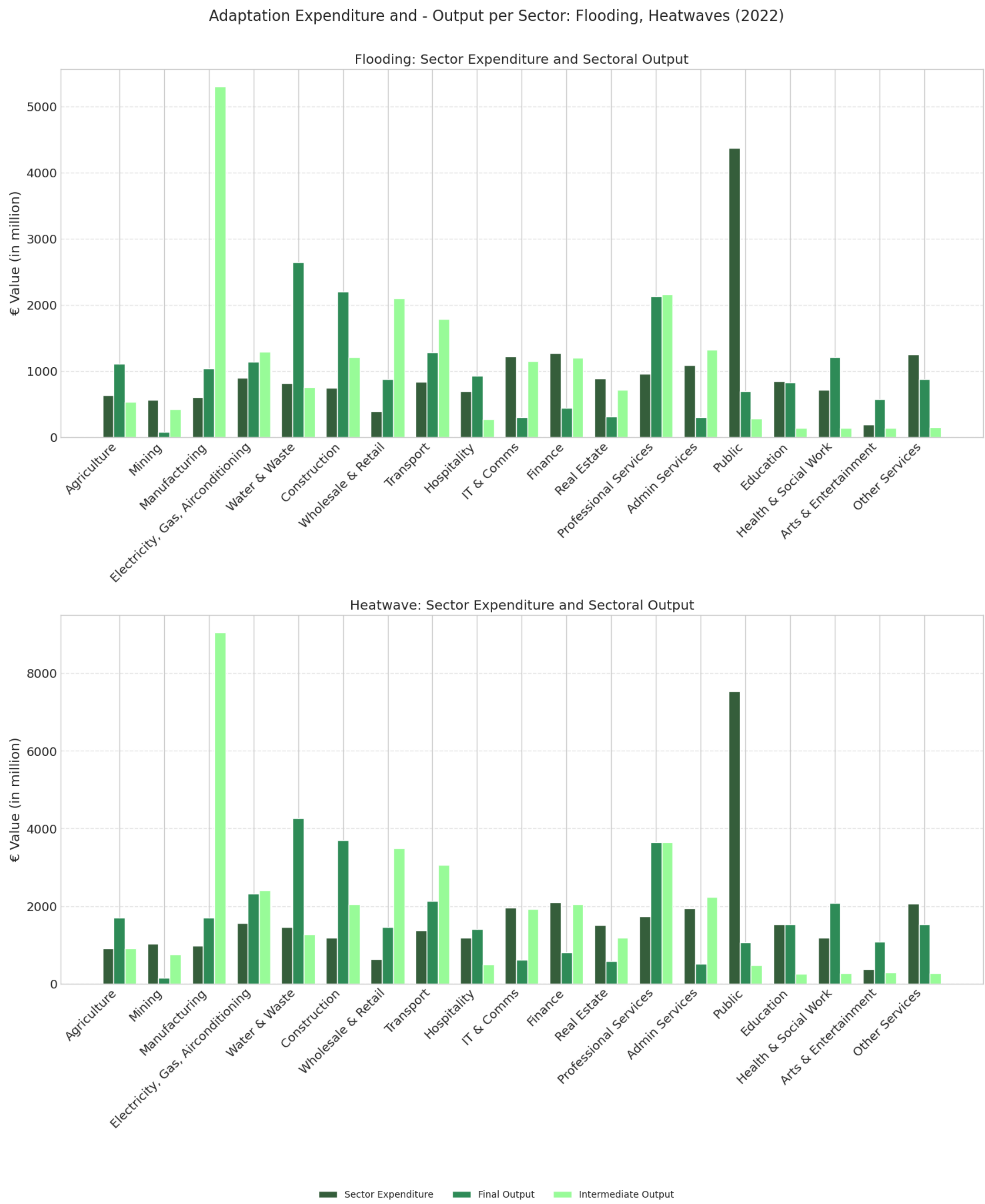

Figure N.2.: Output 2022 per sector

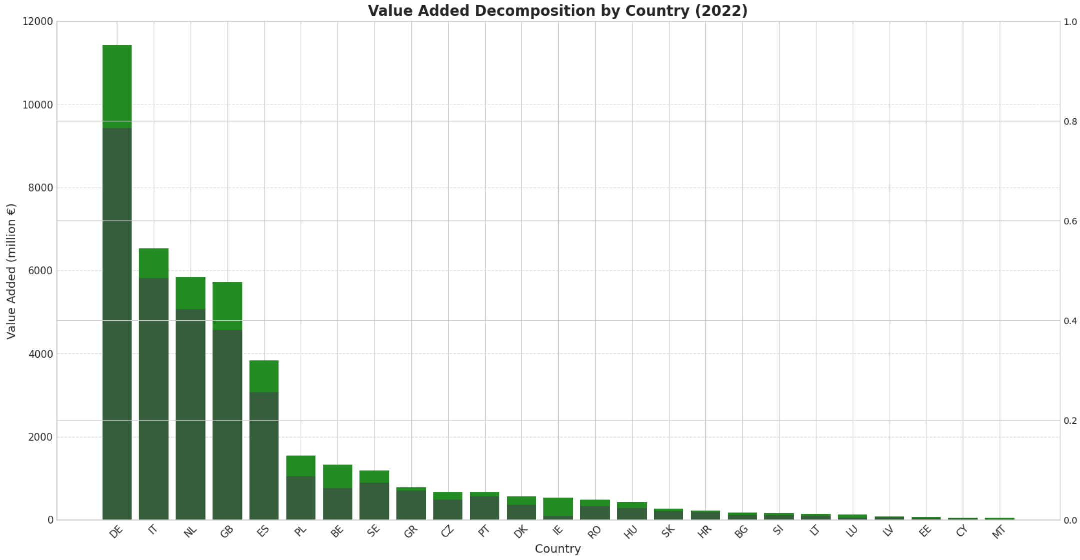

Figure N.3.: GVC 2022 per country

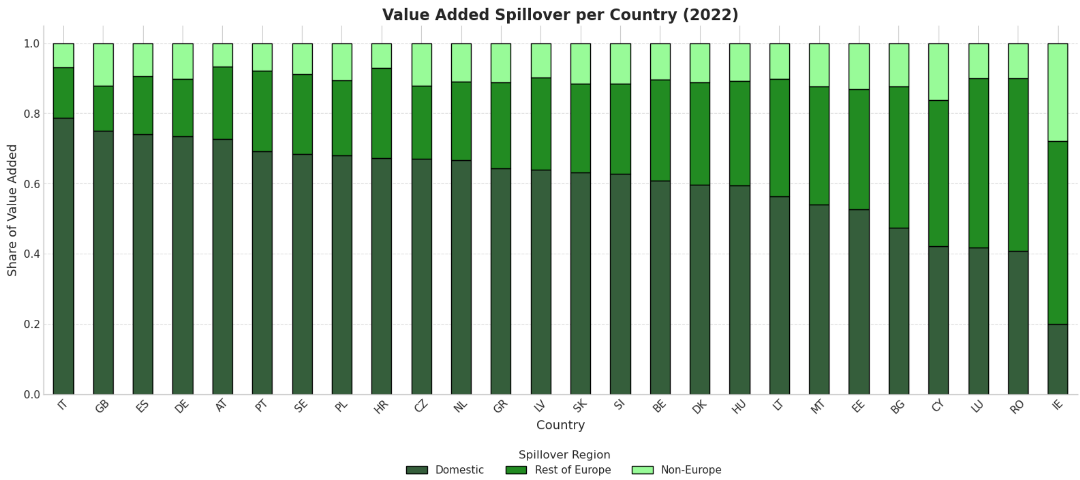

Figure N.4.: Spillover 2022 per country

O Graphs for the Year 2021

This appendix presents the key graphical results for 2021.

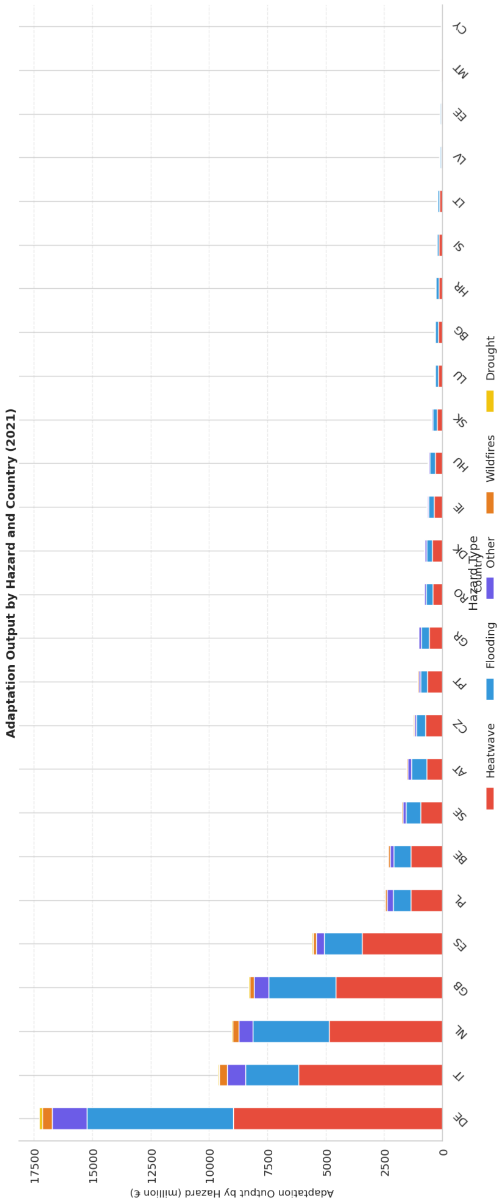

Figure O.1.: Output 2021 per country

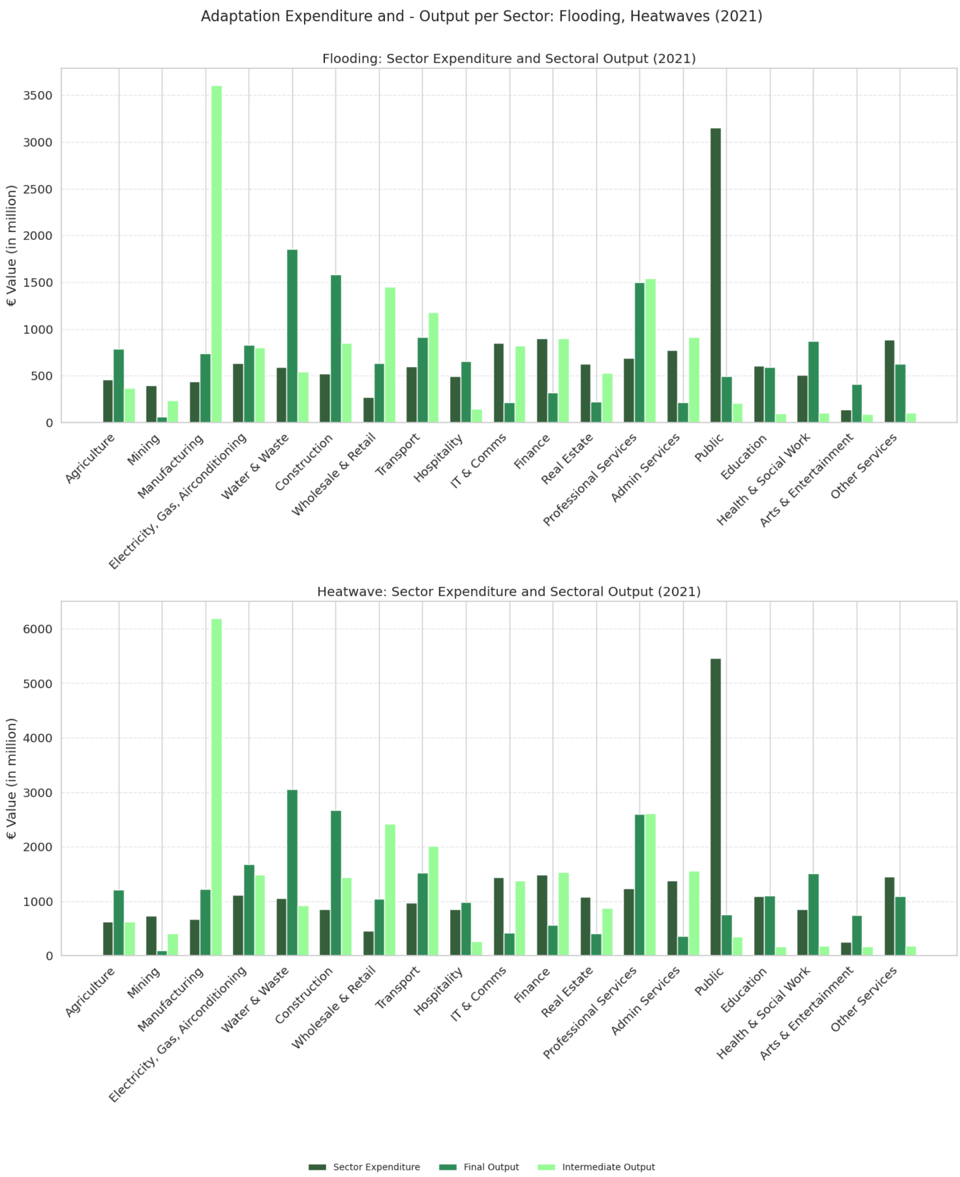

Figure O.2.: Output 2021 per sector

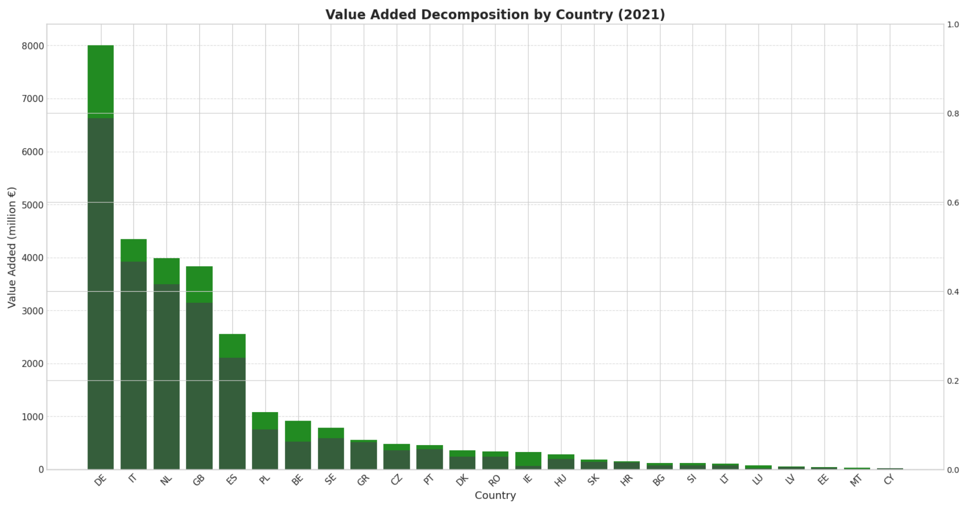

Figure O.3.: GVC 2021 per country

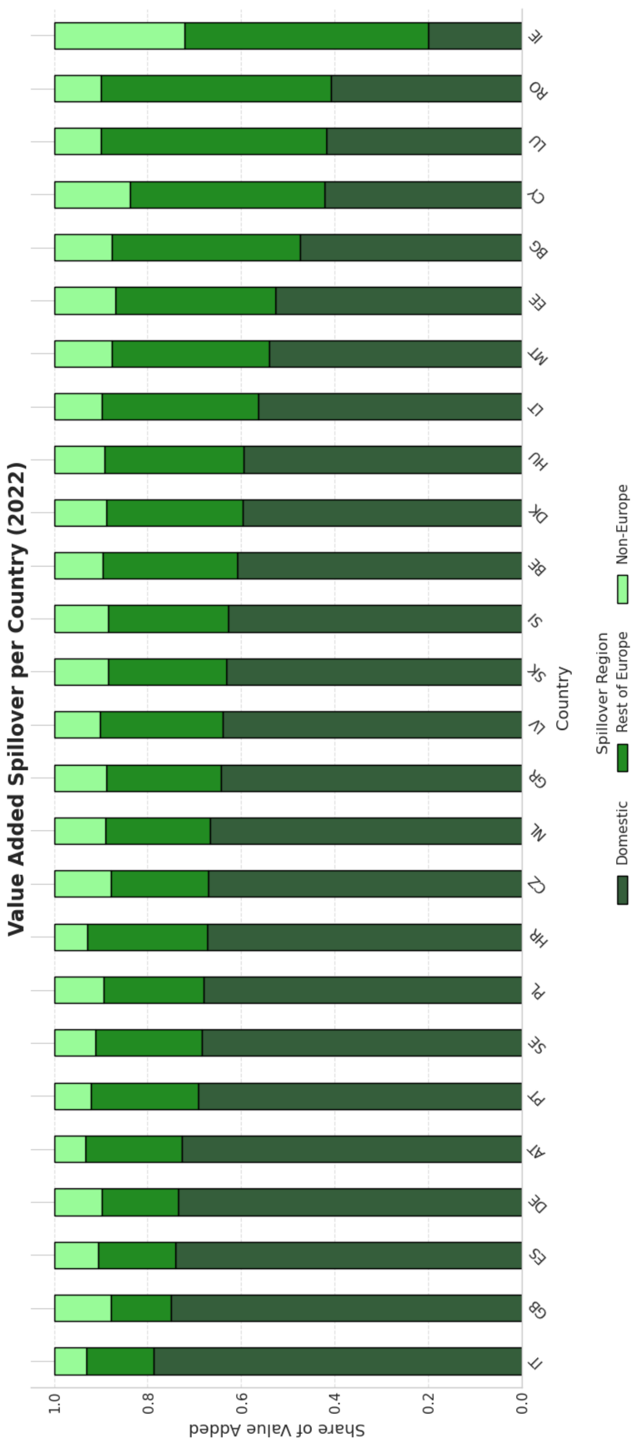

Figure O.4.: Spillover 2021 per country

Bibliography

ADB, A. A., D. Furceri, and P. T. IMF (2016). The macroeconomic effects of public investment: Evidence from advanced economies. *Journal of Macroeconomics 50*, 224–240.

Agrawala, S., M. Carraro, N. Kingsmill, E. Lanzi, M. Mullan, and G. Prudent-Richard (2011). Private sector engagement in adaptation to climate change: approaches to managing climate risks.

Alatriste-Contreras, M. G. (2015). The relationship between the key sectors in the european union economy and the intra-european union trade. *Journal of Economic Structures 4*(1), 1–24.

Aligishiev, Z., M. Bellon, and E. Massetti (2022, March). Macro-fiscal implications of adaptation to climate change. Staff Climate Note 2022/002, International Monetary Fund, Washington, DC.

Arndt, S. W. and H. Kierzkowski (2001). *Fragmentation: New production patterns in the world economy*. OUP Oxford.

Asian Development Bank (2023). Multi-regional input-output database (adb-mrio). https://kidb.adb.org/mrio. Accessed: 2025-05-05.

Auerbach, A. J. and Y. Gorodnichenko (2012). Measuring the output responses to fiscal policy. *American Economic Journal: Economic Policy 4*(2), 1–27.

Augier, P., M. Gasiorek, and C. Lai Tong (2005). The impact of rules of origin on trade flows. *Economic Policy 20*(43), 568–624.

Avelino, A. F. T., A. Franco-Solís, and A. Carrascal-Incera (2021, December). Revisiting the Temporal Leontief Inverse: New Insights on the Analysis of Regional Technological Economic Change. *Structural Change and Economic Dynamics 59*, 79–89.

Baldwin, R. et al. (2012). Global supply chains: Why they emerged, why they matter, and where they are going. *CEPR Discussion Papers*.

Bank of Greece (2016). Excerpts from the national climate change adaptation strategy. Technical report, Bank of Greece.

Becker, J., M. Niemann, and S. Halsbenning (2019). Contribution to growth: European public procurement. Study PE 631.048, European Parliament, Directorate-General for Internal Policies.

Bess, R., Z. O. Ambargis, et al. (2011). Input-output models for impact analysis: Suggestions for practitioners using rims ii multipliers. In *50th Southern Regional Science Association Conference*, pp. 23–27. Citeseer.

Biesbroek, R. and R. Swart (2019). Adaptation policy at supranational level? evidence from the european union. In *Research handbook on climate change adaptation policy*, pp. 194–211. Edward Elgar Publishing.

Biesbroek, R., R. Swart, T. R. Carter, C. Cowan, T. Henrichs, H. Mela, M. D. Morecroft, and D. Rey (2010). Europe adapts to climate change: Comparing national adaptation strategies. *Global Environmental Change 20*(3), 440–450.

Borbon-Garcia, M., D. Muir, N. Treetampinich, and Y. Wu (2023). Mario: A multi-region input–output framework to support economic policy analysis. https://iioa.org/conferences/29th/papers/files/4743_IMF-MARIOPAPERIIOA2023.pdf. Accessed: 2025-06-02.

Borin, A. and M. Mancini (2023). Measuring what matters in value-added trade. *Economic Systems Research 35*(4), 586–613.

Brown, L. H. (2022). Addressing the adaptation finance gap: Scaling up investment in climate change adaptation using blended finance solutions.

Bullard, C. W. and A. V. Sebald (1977). Effects of parametric uncertainty and technological change on input-output models. *The Review of Economics and Statistics*, 75–81.

Bullard, C. W. and A. V. Sebald (1988). Monte carlo sensitivity analysis of input-output models. *The Review of Economics and Statistics*, 708–712.

Buth, M., W. Kahlenborn, J. Savelsberg, N. Becker, P. Bubeck, S. Kabisch, C. Kind, A. Tempel, and F. Tucci (2015, November). Germany's vulnerability to climate change. Technical report, climate change 24/2015, German Environment Agency (Umweltbundesamt), Dessau-Roßlau, Germany.

Caggiani, L., M. Ottomanelli, and M. Dell'Orco (2014). Handling uncertainty in multi regional input-output models by entropy maximization and fuzzy programming. *Transportation Research Part E: Logistics and Transportation Review 71*, 159–172.

Chambwera, M., G. Heal, C. Dubeux, S. Hallegatte, L. Leclerc, A. Markandya, B. A. McCarl, R. Mechler, and J. E. Neumann (2014, April). Chapter 17 - Economics of adaptation. Cambridge University Press.

Chen, Q., E. Dietzenbacher, B. Los, and C. Yang (2010). Partially endogenized consumption: a new method to incorporate the household sector into input-output models. In *The eighteenth international input-output conference, Sydney*.

Chen, W., B. Los, and M. P. Timmer (2023). Dimitri: Dynamic input–output model with investment, technological renewal and international linkages. Technical report, University of Groningen, GGDC Working Paper. Forthcoming / Working Paper.

Chiabai, A., A. Hunt, I. Galarraga, M. Lago, J. Rouillard, E. S. de Murieta, A. Tepes, J. Troeltzsch, and P. Watkiss (2015). Using cost and benefits to assess adaptation options. *ECONADAPT Project, Work Package Number WP3, Deliverable 3*.

Cigna, S., V. Gunnella, and L. Quaglietti (2022). Global value chains: Measurement, trends and drivers. Technical Report 289, European Central Bank. Accessed: 2025-06-18.

Cimato, F. and M. Mullan (2010). Adapting to climate change: Analysing the role of government. *research.fit.edu*.

Climate ADAPT (2024, July). Country Profiles. https://climate-adapt.eea.europa.eu/en/countries-regions/countries.

Climate Investment Funds (2016, December). CTF results report 2016.

Climate Policy Initiative (2020). A snapshot of global adaptation investment and tracking methods. Accessed: 2025-06-03.

Climate Policy Initiative (2023). *Global Landscape of Climate Finance 2023*. Climate Policy Initiative.

Clouse, C., J. Thorvaldson, and G. J. Jolley (2023). Impact factors: Methodological standards for applied input-output analysis. *Journal of Regional Analysis & Policy 53*(2), 1–14.

Cochu, A., T. Hausotter, and M. Henzler (2019, August). The Roles of the Private Sector in Climate Change Adaptation - an Introduction. https://weadapt.org/knowledge-base/climate-finance/the-roles-of-the-private-sector-in-climate-change-adaptation/.

Copernicus Climate Change Service (2024). European state of the climate 2024. Accessed: 2025-06-03.

Cortekar, J., S. Bender, M. Brune, and M. Groth (2016). Why climate change adaptation in cities needs customised and flexible climate services. *Climate Services 4*, 42–51.

Cortés Arbués, I., T. Chatzivasileiadis, S. Storm, O. Ivanova, and T. Filatova (2025). Private investments in climate change adaptation are increasing in europe, although sectoral differences remain. *Communications Earth & Environment 6*(1), 1–12.

Coughlin, C. C. and T. B. Mandelbaum (1991). A consumer's guide to regional economic multipliers. *Federal Reserve Bank of St. Louis Review 73*(January/February 1991).

CPI (2024, September). Tracking and mobilizing private sector climate adaptation finance.

Crawford, A. and C. Church (2019). The Role of the Private Sector in Supporting Climate Adaptation. Technical report, International Institute for Sustainable Development (IISD).

Cwik, T. and V. Wieland (2011). Keynesian government spending multipliers and spillovers in the euro area. *Economic Policy 26*(67), 493–549.

de Jong, J., M. Ferdinandusse, J. Funda, and I. Vetlov (2017, February). The effect of public investment in europe: A model-based assessment. ECB Working Paper Series 2021, European Central Bank. ECB Working Paper No. 2021.

Deleidi, M., F. Iafrate, and E. S. Levrero (2023). Government investment fiscal multipliers: evidence from euro-area countries. *Macroeconomic dynamics 27*(2), 331–349.

Dietzenbacher, E. and J. A. van der Linden (1997). Multiplier effects in the dutch economy: An analysis with the input-output model. *Economic Systems Research 9*(3), 249–267.

Dutch Ministry of Infrastructure and Water Management (2021, September). Delta Programme 2022: Continuing the work on water safety, freshwater availability and spatial adaptation. Accessed: 2025-06-15.

Dzebo, A. (2019, October). Effective governance of transnational adaptation initiatives. *International Environmental Agreements: Politics, Law and Economics 19*(4), 447–466.

Eichengreen, B. J. and D. A. Irwin (1996). *The role of history in bilateral trade flows*, Volume 5565. National Bureau of Economic Research Cambridge, Mass.

Eicher, T. S. and C. Henn (2011). In search of wto trade effects: Preferential trade agreements promote trade strongly, but unevenly. *Journal of International Economics 83*(2), 137–153.

Eker, S. and J. H. Kwakkel (2018). Including robustness considerations in the search phase of many-objective robust decision making. *Environmental Modelling & Software 105*, 201–216.

Emonts-Holley, T., A. Ross, and J. Swales (2015). Type ii errors in io multipliers.

Enfield, S. (2020). Private sector markets for climate adaptation and resilience products and services.

European Commission (2021). Forging a climate-resilient europe – the new eu strategy on adaptation to climate change. `https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0082`. COM(2021) 82 final.

European Commission (2025). Slovenia's strategic integrated life project for adaptation – life4adapt. `https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE23-IPC-SI-LIFE4ADAPT-101147797/slovenias-strategic-integrated-life-project-for-adaptation`. Accessed: 2025-06-06.

European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, and World Bank (2009). *System of National Accounts 2008*. New York: United Nations.

European Environment Agency (2018, December). Addressing climate change adaptation in transnational regions in europe. EEA Briefing 17/2018, European Environment Agency, Copenhagen, Denmark.

European Environment Agency (2022). Assessing the costs and benefits of climate change adaptation. Technical report, European Environment Agency. Accessed: 2025-05-26.

European Environment Agency (2023). Economic losses from climate-related extremes in europe. Accessed: 2025-06-03.

European Environment Agency (2024a). Europe's first climate risk assessment: 36 climate risks require urgent action. Accessed: 2025-08-04.

European Environment Agency (2024b, June). Preparing society for climate risks in europe–lessons and inspiration from climate-adapt case studies. Briefing, European Environment Agency, Copenhagen, Denmark.

European Union (2003). Treaty concerning the accession of the czech republic, estonia, cyprus, latvia, lithuania, hungary, malta, poland, slovenia, and slovakia to the european union. Accessed: 2025-06-18.

Eurostat (2025). National accounts aggregates by industry.

Euro-Mediterranean Center on Climate Change (CMCC) (2025, April). Heatsafe: Holistic environmental and social adaptation framework for extreme heat. https://www.cmcc.it/projects/heatsafe-holistic-environmental-and-social-adaptation-framework-for-extreme-heat.

Fankhauser, S. and I. Burton (2011, June). Spending adaptation money wisely. *Climate Policy 11*(3), 1037–1049.

Feás, E. (2023). Decomposition of value added in gross exports: a critical review. *Applied Economic Analysis 31*(93), 182–198.

Feas, E. (2024). *exvatools: Value Added in Exports and Other Input-Output Table Analysis Tools*. R package. Provides functions for value-added decomposition and MRIO analysis.

Frontier Economics (2022). BARRIERS TO FINANCING ADAPTATION ACTIONS IN THE UK.

Gechert, S. and A. Rannenberg (2018). Which fiscal multipliers are regime-dependent? a meta-regression analysis. *Journal of Economic Surveys 32*(4), 1160–1182.

Gereffi, G. and J. Lee (2012). Why the world suddenly cares about global supply chains. *Journal of supply chain management 48*(3), 24–32.

Global Center on Adaptation (2024). State and trends in climate adaptation finance 2024. Technical report, Global Center on Adaptation.

Global Commission on Adaptation (2019). *Adapt Now: A Global Call for Leadership on Climate Resilience*. Global Center on Adaptation.

Global Commission on Adaptation (GCA) (2021). State and trends in ecosystem-based adaptation. Technical report, Global Commission on Adaptation, Rotterdam, The Netherlands.

Grady, P. and R. A. Muller (1988). On the use and misuse of input-output based impact analysis in evaluation. *Canadian Journal of Program Evaluation 3*(2), 49–61.

Haasnoot, M., J. H. Kwakkel, W. E. Walker, and J. ter Maat (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change 23*(2), 485–498.

Hagedorn, M., I. Manovskii, and K. Mitman (2019). The fiscal multiplier. Technical report, National Bureau of Economic Research.

Hall, R. E. (2009). By how much does gdp rise if the government buys more output? Technical report, National Bureau of Economic Research.

Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. *Global Environmental Change 19*(2), 240–247.

Hallegatte, S., A. Shah, R. Lempert, C. Brown, and S. Gill (2012, September). Investment decision making under deep uncertainty: Application to climate change. Technical Report 6193, The World Bank, Policy Research Working Paper Series.

Hanseman, D. J. and E. F. Gustafson (1981). Stochastic input-output analysis: a comment. *The Review of Economics and Statistics*, 468–470.

Hertwich, E. G. (2021). Increased carbon footprint of materials production driven by rise in investments. *Nature Geoscience 14*, 151–155.

Heubaum, H., C. Brandon, T. Tanner, S. Surminski, and V. Roezer (2022, Nov). The triple dividend of building climate resilience: Taking stock, moving forward. Working Paper WRI WP, World Resources Institute. CC BY 4.0.

Howard, S., S. Howard, and S. Howard (2020, January). Quantitative market analysis of the European Climate Services sector – The application of the kMatrix big data market analytical tool to provide robust market intelligence. *Climate Services 17*, 100108.

Hughes, D. W. (2003). Policy uses of economic multiplier and impact analysis. *Choices 18*(2), 25–29.

Hummels, D., J. Ishii, and K.-M. Yi (2001, June). The nature and growth of vertical specialization in world trade. *Journal of International Economics 54*(1), 75–96.

Hötte, K. and S. J. Jee (2022). Knowledge for a warmer world: A patent analysis of climate change adaptation technologies. *Technological Forecasting and Social Change 183*, 121879.

Ilzetzki, E., E. G. Mendoza, and C. A. Végh (2013). How big (small?) are fiscal multipliers? *Journal of monetary economics 60*(2), 239–254.

IMF Research Dept. (2012). *World economic outlook, October 2012: Coping with high debt and sluggish growth*. International Monetary Fund.

IPCC (2023). Climate change 2023: Synthesis report. contribution of working groups i, ii and iii to the sixth assessment report of the intergovernmental panel on climate change. https://www.ipcc.ch/report/sixth-assessment-report-cycle/. Accessed June 2025.

Isard, W. (1966). *Methods of regional analysis*. .

Johnson, R. C. (2018). Accounting for intermediates: Production sharing and trade in value added. *Journal of Economic Perspectives 32*(2), 95–118.

Josephson, A., R. Guerra Su, G. Collins, and K. Jacobs (2024, November). The economics of climate adaptation: An assessment. *arXiv preprint arXiv:2411.16893*.

Kahn, M. E. (2016). The climate change adaptation literature. *Review of Environmental Economics and Policy*.

Kilponen, J., M. Pisani, S. Schmidt, V. Corbo, T. Hledik, J. Hollmayr, S. Hurtado, P. Júlio, D. Kulikov, M. Lemoine, M. Lozej, H. Lundvall, J. R. Maria, B. Micallef, D. Papageorgiou, J. Rysanek, D. Sideris, C. Thomas, and G. de Walque (2015, March). Comparing fiscal multipliers across models and countries in europe. ECB Working Paper 1760, European Central Bank. ECB Working Paper Series No. 1760.

Koopman, R., Z. Wang, and S.-J. Wei (2014). Give credit where credit is due: Tracing value added in global production chains. *American Economic Review 104*(8), 459–494.

Kratena, K. (2024, April). Effective demand, wages and prices, and the multiplier. *Economic Systems Research 36*(2), 226–248.

Kratena, K. and G. Streicher (2017). Fiscal policy multipliers and spillovers in a multi-regional macroeconomic input-output model. Technical report, WIFO Working Papers.

Kratena, K. and U. Temursho (2017). Dynamic Econometric Input-Output Modeling: New Perspectives. In R. Jackson and P. Schaeffer (Eds.), *Regional Research Frontiers - Vol. 2: Methodological Advances, Regional Systems Modeling and Open Sciences*, pp. 3–21. Cham: Springer International Publishing.

Kwakkel, J. H. (2017). The exploratory modeling workbench: An open source toolkit for exploratory modeling, scenario discovery, and multi-objective robust decision making. *Environmental Modelling & Software 96*, 239–250.

Lacambra, C., I. Leroux, A. Cartwright, P. Johnston, C. Munera, P. Tiongson, J. Lacambra, and T. E. Downing (2020). Private markets for climate resilience: Global report.

Leitner, M., T. Dworak, K. Johnson, and A. Prutsch (2021). Using Key Type Measures to report climate adaptation action in the EEA member countries. *2021*.

Lenzen, M. (2001). A generalized input-output multiplier calculus for australia. *Economic Systems Research 13*(1), 65–92.

Lenzen, M., K. Kanemoto, D. Moran, and A. Geschke (2012). Mapping the structure of the world economy. *Environmental Science & Technology 46*(15), 8374–8381.

Lenzen, M., L.-L. Pade, and J. Munksgaard (2004). Co2 multipliers in multi-region input-output models. *Economic Systems Research 16*(4), 391–412.

Lenzen, M., R. Wood, and T. Wiedmann (2010, March). Uncertainty Analysis for Multi-Region Input–Output Models – a Case Study of the Uk's Carbon Footprint. *Economic Systems Research 22*(1), 43–63.

Leontief (1936a). Quantitative Input and Output Relations in the Economic Systems of the United States on JSTOR. https://www.jstor.org/stable/1927837.

Leontief, W. (1986). *Input-Output Economics* (2nd ed ed.). New York: Oxford University Press.

Leontief, W. W. (1936b). Quantitative input and output relations in the economic systems of the united states. *The review of economic statistics*, 105–125.

Leontief, W. W. (1951). The structure of american economy, 1919-1929: An empirical application of equilibrium analysis. *(No Title)*.

Li, R. and S. Ge (2022). Towards economic value-added growth without carbon emission embodied growth in north–north trade—an empirical analysis of us-german trade. *Environmental Science and Pollution Research 29*(29), 43874–43890.

Linnenluecke, M. K., A. Griffiths, and M. I. Winn (2013). Firm and industry adaptation to climate change: a review of climate adaptation studies in the business and management field. *Wiley Interdisciplinary Reviews: Climate Change 4*(5), 397–416.

Los, B., R. Gouma, M. Timmer, and P. IJtsma (2014). Note on the construction of wiots in previous years prices. In *Technical Report*. Technical report, WIOD.

Magnan, A. K., E. L. F. Schipper, M. Burkett, S. Bharwani, I. Burton, S. Eriksen, F. Gemenne, J. Schaar, and G. Ziervogel (2016). Addressing the risk of maladaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change 7*(5), 646–665.

Martin, J., I. Mejean, and M. Parenti (2023). Relationship stickiness, international trade, and economic uncertainty. *Review of Economics and Statistics*, 1–45.

Massetti, E. and R. Mendelsohn (2018, July). Measuring Climate Adaptation: Methods and Evidence. *Review of Environmental Economics and Policy 12*(2), 324–341.

Mechler, R. (2016). Reviewing estimates of the economic efficiency of disaster risk management: opportunities and limitations of using risk-based cost–benefit analysis. *Natural Hazards 81*(3), 2121–2147.

Mendelsohn, R. (2000, June). Efficient Adaptation to Climate Change. *Climatic Change 45*(3), 583–600.

Mendelsohn, R. (2012). The economics of adaptation to climate change in developing countries. *Climate Change Economics 3*(02), 1250006.

Mi, Z., J. Meng, H. Zheng, Y. Shan, Y.-M. Wei, and D. Guan (2018). A multi-regional input-output table mapping china's economic outputs and interdependencies in 2012. *Scientific data 5*(1), 1–12.

Miller, R. E. and P. D. Blair (2009). *Input-output analysis: foundations and extensions*. Cambridge university press.

Miroudot, S. and C. Cadestin (2017). Services in global value chains: From inputs to value-creating activities.

Miroudot, S. and M. Ye (2021). Decomposing value added in gross exports. *Economic Systems Research 33*(1), 67–87.

Miyazawa, K. and K. Miyazawa (1976). *Input-output analysis and interrelational income multiplier as a matrix*. Springer.

Nagengast, A. J. and R. Stehrer (2016, September). Accounting for the Differences Between Gross and Value Added Trade Balances. *The World Economy 39*(9), 1276–1306.

OECD (2019). Guide to oecd's trade in value added (tiva) indicators, 2018 edition.

OECD (2023). Guide to OECD TiVA Indicators, 2023 Edition. Technical report, OECD Publishing, Paris.

OECD (2023). Trade in value added (tiva) 2023: Eu27 (2020) results. Technical report, OECD. Accessed: 2025-06-12.

OECD (2024). Climate change adaptation: Policies for a resilient future. Technical report, OECD. Chapter 1.4 recommends the triple dividend framework for robust appraisal and prioritisation of adaptation strategies.

OECD (2024a). *Financing Climate Resilience: Mobilizing Private Investment for Adaptation*. OECD.

OECD (2024b, March). Sustainability-linked bonds. *44*.

OECD (2025). Trade in value-added (tiva). `https://www.oecd.org/en/topics/sub-issues/trade-in-value-added.html`. OECD overview page on TiVA; accessed June11,2025.

Oosterhaven, J., K. R. Polenske, and G. J. Hewings (2019). Modern regional input–output and impact analysis. In *Handbook of regional growth and development theories*, pp. 505–525. Edward Elgar Publishing.

Osberghaus, D., A. Dannenberg, T. Mennel, and B. Sturm (2010). The role of the government in adaptation to climate change. *Environment and Planning C: Government and Policy 28*(5), 834–850.

Oulton, N., A. Rincon-Aznar, L. Samek, and S. Srinivasan (2018). Double deflation: theory and practice.

Owen, A., R. Wood, J. Barrett, and A. Evans (2016). Explaining value chain differences in mrio databases through structural path decomposition. *Economic Systems Research 28*(2), 243–272.

Pauw, W. P., L. Kempa, U. Moslener, C. Grüning, and C. Çevik (2022, January). A focus on market imperfections can help governments to mobilize private investments in adaptation. *Climate and Development 14*(1), 91–97.

Pfeiffer, P., J. Varga, et al. (2023). Quantifying spillovers of coordinated investment stimulus in the eu. *Macroeconomic Dynamics 27*(7), 1843–1865.

Pisu, M., H. Costa, F. M. D'Arcangelo, Y. Hemmerlé, T. Kruse, and L. Lutz (2024, December). Accelerating climate adaptation: A framework for assessing and addressing adaptation needs and priorities. Technical Report 35, OECD, Paris.

Proudman, J. and S. J. Redding (1997). Persistence and mobility in international trade.

Pörtner, H.-O., D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge, UK and New York, NY, USA: Cambridge University Press. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Quandt, R. E. (1958). Probabilistic errors in the leontief system. *Naval Research Logistics Quarterly 5*(2), 155–170.

Quandt, R. E. (1959). On the solution of probabilistic leontief systems. *Naval Research Logistics Quarterly 6*(4), 295–305.

Ramey, V. A. (2019). Ten years after the financial crisis: What have we learned from the renaissance in fiscal research? *Journal of Economic Perspectives 33*(2), 89–114.

Roggero, M., L. Kähler, and A. Hagen (2019). Strategic cooperation for transnational adaptation: Lessons from the economics of climate change mitigation. *International Environmental Agreements: Politics, Law and Economics 19*(4), 395–410.

Roy, J. R. and J.-C. Thill (2004). Spatial interaction modelling. *Papers in Regional Science 83*(1), 339–361.

Rozer, J. P., C. Smith, K. Johnson, et al. (2021). Multiple sources of uncertainty in climate adaptation planning. *Climate Risk Management 33*, 100 450.

Römisch, R. (2020). Estimating demand spillovers of eu cohesion policy using european regional input-output tables. Technical report, The Vienna Institute for International Economic Studies (wiiw). Accessed: 2025-06-18.

Saccone, D., P. Della Posta, E. Marelli, and M. Signorelli (2022). Public investment multipliers by functions of government: An empirical analysis for european countries. *Structural Change and Economic Dynamics 60*, 531–545.

Schaer, C. and N. D. Kuruppu (2018). Private-sector action in adaptation: Perspectives on the role of micro, small and medium size enterprises. Technical report.

Stadler, K., R. Wood, T. Bulavskaya, C.-J. Södersten, M. Simas, S. Schmidt, A. Usubiaga, J. Acosta-Fernández, J. Kuenen, M. Bruckner, S. Giljum, S. Lutter, S. Merciai, J. H. Schmidt, M. C. Theurl, C. Plutzar, T. Kastner, N. Eisenmenger, K.-H. Erb, A. Koning, and A. Tukker (2021, October). EXIOBASE 3.

STAR-FLOOD (2016, March). STAR-FLOOD: Strengthening and redesigning european flood risk practices. Final Report Grant agreement ID 308364, CORDIS, European Commission, Belgium.

Stehrer, R., J. M. Rueda-Cantuche, A. F. Amores, and D. Zenz (2024). Wrapping input–output multipliers in confidence intervals. *Journal of Economic Structures 13*(1), 17.

Stern, N. (2008, May). The Economics of Climate Change. *American Economic Review 98*(2), 1–37.

Surminski, S., M. Di Mauro, J. A. R. Baglee, R. K. Connell, J. Hankinson, A. R. Haworth, B. Ingirige, and D. Proverbs (2018). Assessing climate risks across different business sectors and industries: an investigation of methodological challenges at national scale for the uk. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 376*(2121), 20170307.

Tanner, T., A. Bahadur, and M. Moench (2015). *The Triple Dividend of Resilience: Realising Development Goals through the Multiple Benefits of Disaster Risk Management*. Washington, DC and London: Global Facility for Disaster Reduction and Recovery (GFDRR) and Overseas Development Institute (ODI). Official report introducing the Triple Dividend framework.

Tanner, T., S. Surminski, E. Wilkinson, R. Reid, J. Rentschler, and S. Rajput (2015). The triple dividend of resilience: Realising development goals through the multiple benefits of disaster risk management.

Ten Raa, T. (1994). On the methodology of input-output analysis. *Regional Science and Urban Economics 24*(1), 3–25.

Timmer, M. P., E. Dietzenbacher, B. Los, R. Stehrer, and G. J. de Vries (2015). An illustrated user guide to the world input–output database: the case of global automotive production. *Review of International Economics 23*(3), 575–605.

Treville, A., C. Franco de Los Rios, G. Melica, M. Baldi, M. Clemente, and P. Bertoldi (2022). Gcom - mycovenant, 2021, second release.

Uchida, Y. and K. Oyamada (2017). Evaluating the asian international input-output table in comparison with the three major multiregional input-output tables. *IDE Discussion Paper 663*.

United Nations Environment Programme (2022). *Adaptation Gap Report 2022: Too Little, Too Slow*. UNEP.

Viguié, V. and S. Hallegatte (2012). Trade-offs and synergies in urban climate policies. *Nature Climate Change 2*(5), 334–337.

Wang, Z., S.-J. Wei, and K. Zhu (2013). Quantifying international production sharing at the bilateral and sector levels. Technical report, National Bureau of Economic Research.

Weber, C. L. (2008). Uncertainties in constructing environmental multiregional input-output models. In *International input-output meeting on managing the environment*, Volume 10.

Weber, C. L. and H. S. Matthews (2007). Embodied environmental emissions in us international trade, 1997- 2004.

Weiss, S. J. and E. C. Gooding (1970). Estimation of differential employment multipliers in a small regional economy. In *Regional Economics: A Reader*, pp. 55–68. Springer.

Werkgroep Klimaatadaptatie (2023, december). Klimaatadaptatie in een stroomversnelling: Financiële sector en overheid samen aan de slag. Technical report, De Nederlandsche Bank. Toegankelijk op 26 mei 2025.

Wiedmann, T. and J. Minx (2009). A review of recent developments in the application of input–output analysis to carbon footprinting. *Economic Systems Research 21*(3), 187–216.

Wilby, R. L. (2022, March). Well informed adaptation decision making under uncertainty. Working Paper No. 12, Climate Change Advisory Council, Ireland.

World Bank (2024, May). *Valuing Climate Adaptation Helps Us Orient Our Compass Toward Effective and Resilient Pathways: Climate Adaptation Costing in a Changing World*. World Bank.

World Bank (2025). World development indicators: Inflation, gdp deflator (annual %). https://databank.worldbank.org/reports.aspx?source=2&series=NY.GDP.DEFL.KD.ZG&country=ARG. Last updated: 2025-04-15. License: CC BY-4.0. Source: World Bank national accounts data and OECD National Accounts data files.

World Bank Group (2021). *Unlocking Private Climate Finance in Emerging Markets: Climate-Smart Investment Opportunities*. World Bank.

Worldbank Group (2021). Enabling private investment in climate adaptation & resilience.

Xie, R., Y. Zhao, and L. Chen (2020). Structural path analysis and its applications: literature review. *National Accounting Review 2*(1), 83–94.

Zheng, H., J. Többen, E. Dietzenbacher, D. Moran, J. Meng, D. Wang, and D. Guan (2022). Entropy-based chinese city-level mrio table framework. *Economic Systems Research 34*(4), 519–544.

Colophon

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