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MODELLING GLOBAL VALUE CHAINS AND SUSTAINABILITY IMPACTS

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ABSTRACT

Samuel Rintamäki: Modelling Global Value Chains and Sustainability Impacts
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The need to address sustainability impacts beyond local borders has increased in recent years with introduction of new global agreements, legislation, and increased public awareness. Now, both public and private organisations analyse the total effectiveness of investments before deciding on significant ventures. This has made practitioners and researchers on the field to develop and extend new and existing methods and tools of effectiveness evaluation to cover the induced foreign impacts. Consequently, significance of global value chain analysis has increased as it enables the examination of global sustainability impacts within the domain of a single statistical application. This analysis allows the detailed study of geographically disperse value chain connections and tracing of the linchpin industries that have a significant effect on projects economic, environmental, and social impacts on different regional levels.

This thesis acknowledges the significance of global value chain design on investments total sustainability impacts and brings forth the idea of utilizing global value chain analysis in optimizing the local and global sustainability impacts of foreign ventures. The research was carried in co-operation with a case company that is an expert organization in the field of effectiveness evaluation and the study scours the literature to find the current top-approaches to local to global to local impact assessments. Besides creating awareness on global effectiveness evaluation and assembling the top statistical approaches, databases and tools for impact analysis, one of the study's aims is to apply one of the methods found to evaluate a timely real-life investment scenario called the Facility and assess the uncertainties and potential of the MRIO-method applied. The research was carried out following the constructive research process and the results are based on simulations with a constructed multiregional input-output model with Finnish subnational coverage.

Dynamic computable general equilibrium and multiregional input-output models are recognized as the current top-approaches for cost-effective impact evaluations. Well-constructed CGE models capture the local economic impacts of ventures in very good detail but lack in their capabilities to capture the induced global value chain impacts whereas global MRIO models are very good tools to capture the wide-spread sustainability impacts of investments and to analyse global value chain connections but hinder by being static and based on harmonized historical data. Based on these findings applying a GMRIO model in sustainability impact assessments of international level is recommended, though hybrid CGE-MRIO models are recognized as the most potential avenues for future model development.

The main result of the study is the constructed statistical modelling tool that can be used to trace global value chain connections and to evaluate and optimize the effectiveness and sustainability impacts of foreign investments. The model test scenario proves the importance of global value chain analysis by showcasing that Finland would be able to capture up to 2 % more positive socio-economic impacts from the received Facility grants by allocating investments towards less-populated regions of the nation in comparison to distributing them according to the national economic structure whilst keeping the changes to environmentally negative impacts at very moderate level. Additionally, it is displayed that mining and quarrying industry of the rest of the world region is the global linchpin industry as it receives second to most economic impacts from all of the 338,5 billion euros grants simulated despite all of the money being directly allocated to EU-27 countries, highlighting the potential of global value chain analysis in targeting the global development focus.

Keywords: Global value chains, effectiveness, foreign investments, multiregional input-output, sustainability

TIIVISTELMÄ

Samuel Rintamäki: Globaalien arvoketjujen ja kestävyysvaikutusten mallintaminen
Diplomityö, 136 sivua, 8 liitettä
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Maan rajat ylittävien vaikutusten huomioiminen osana kestävyysarviointeja on kasvanut viime vuosina uusien globaalit sopimuksien, lainsäädännön ja yleisen tietoisuuden kasvamisen seurauksena. Nykyään sekä julkiset että yksityiset organisaatiot analysoivat investointiensa vaikuttavuutta ennen lopullista päätöstä niiden kohtalosta. Tästä johtuen tutkijat, sekä muut alan ammattilaiset ovat kehittäneet uudet ja jo olemassa olevat arviointimenetelmät ja -työkalut kattamaan myös välilliset globaalit vaikutukset. Tämän seurauksena, globaalien arvoketjujen analyysien merkitys on kasvanut, niiden kyetessä arvioimaan maailmanlaajuisia kokonaiskestävyysvaikutuksia yksittäisten tilastollisten mallien avulla. Kyseisen analyysit mahdollistavat maantieteellisesti hajaantuneiden alueiden arvoketjukytkösten yksityiskohtaisen tarkastelun, sekä projektien taloudellisten, ympäristö ja sosiaalisten vaikutusten kannalta keskeisten toimialojen tunnistamisen.

Tämä diplomityö tunnustaa globaalien arvoketjujen rakenteiden merkityksen investointien kokonaisvaikutuksille ja esittää idean globaalien arvoketjujen analyysin hyödyntämisestä ulkomaa-investointien paikallisten ja maailmanlaajuisten kestävyysvaikutusten optimoimiseksi. Tämä tutkimus toteutettiin yhteistyössä vaikuttavuuden arviointiin erikoistuneen yrityksen kanssa, ja tunnistaa kirjallisuudesta tämänhetkiset parhaat menetelmät paikallisten ja globaalien vaikutusten arviointiin. Tutkimuksen päätavoite on globaalin vaikuttavuuden arvioinnin tietoisuuden lisääminen ja tähän liittyvien keskeisten menetelmien, tietokantojen ja työkalujen kokoaminen. Toinen keskeinen tavoite on tutkia tarkemmin yhtä tunnistetuista menetelmistä ja arvioida MRIO-mallinukseen liittyviä epävarmuuksia ja potentiaalia ajankohtaisen reaalimaailman investoinnin vaikutusten analyysin kautta. Tutkimuksessa sovellettiin konstruktiivista tutkimusotetta ja työn tulokset pohjautuvat simulointeihin konstruoidulla monialueellisella panos-tuotos mallilla, joka kattaa sekä kansainväliset että Suomen suuralueiden väliset arvoketjut.

Tutkimuksessa tunnistettiin dynaamisten yleisen tasapainon ja monialueellisten panos-tuotos mallien olevan tämänhetkiset parhaat menetelmät kustannustehokkaaseen vaikutusten arviointiin. Hyvin rakennetut CGE-mallit arvioivat hankkeiden paikallisia taloudellisia vaikutuksia todella tarkalla tasolla, mutta kattavat globaalien arvoketjujen kytkösten synnyttämät välilliset vaikutukset puutteellisesti. MRIO mallit ovat puolestaan hyviä työkaluja laajasti leviävien kestävyysvaikutusten ja globaalien arvoketjujen kytkösten analysointiin, mutta niiden varjopuolena on mallien staattisuus ja pohjautuminen harmonisoituun historialliseen dataan. Löydöksien perusteella, GMRIO mallin soveltaminen kansainvälisen tason kestävyysvaikutusten arvioinneissa on suositeltavaa, vaikkakin CGE-MRIO hybridimallit nähdään potentiaalisimpina suuntina mallien jatkokehitykselle.

Tutkimuksen päätuotos on konstruktioitu tilastollinen mallinnustyökalu, jonka avulla voidaan jäljittää globaalien arvoketjujen kytköksiä, sekä arvioida ja optimoida ulkomaainvestointien vaikuttavuutta ja kestävyysvaikutuksia. Mallin testiskenaario todistaa globaalien arvoketjujen analyysin merkityksen, osoittamalla Suomen kansantalouden tavoittavan 2 % enemmän positiivisia sosioekonomisia vaikutuksia EU-tukipaketin avustuksista kohdentamalla tähän liittyvät investoinnit harvemmin asutuille alueille sen sijaan, että investoinnit kohdennettaisiin nykyisen kansantalouden rakenteen pohjalta, ilman suurta vaikutusta ympäristövaikutuksiin. Tämän lisäksi muun maailman kaivostoiminta ja louhinta toimiala tunnistetaan globaalien arvoketjujen keskeiseksi toimialaksi, sen tavoittaessa toiseksi eniten globaaleja taloudellisia vaikutuksia testiskenaariossa, huolimatta siitä, että kaikki 338,5 miljardia euroa tukia simuloidaan EU-27 alueelle, korostaen globaalien arvoketjujen analyysin potentiaalia globaalien kehitystoimenpiteiden kohdistamisessa.

Avainsanat: Globaalit arvoketjut, vaikuttavuus, ulkomaan investoinnit, monialueellinen panos-tuotos, kestävyys

Tämän julkaisun alkuperäisyys on tarkastettu Turnitin OriginalityCheck –ohjelmalla.

PREFACE

Submission of this master’s thesis marks the end of the most wonderful chapter of my life that I wouldn’t wish to end. Throughout my university journey I’ve met a lot of amazing people both in Tampere and around the world and learned so much that I’ve already forgot half of it. And despite recent times being very restricted, remote and rough for all of us I shall cherish my student days until the end of times.

I wish to thank Ramboll Finland for presenting me with an interesting and demanding topic for this research that I would’ve never came up with on my own. The process has been challenging, absorbing and rewarding but most of all educational. A big thanks to Heikki Savikko for your insights, support, and insistency for well-founded statements. You stopped me to think, discover and apprehend when I instinctively steamrolled ahead which I truly appreciate. Also, I want to thank my university examiners Leena and Aki for your advice throughout the process and everyone else that’s been part of this journey.

Lastly, friends & family. Your support, distractions and company means a great deal to me. You kept me on the right track all throughout the research process, making the busy days busier, sunny days sunnier and the though days untougher. The grandest of gratitude to all of you!

Tampere, 31 August 2021

Samuel Rintamäki

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BAU	Business as usual
CBA	Consumption based accounting
CGE	Computable general equilibrium
CES	Constant elasticities of substitution
CPI	Consumer price index
DCGE	Dynamic computable general equilibrium
DEM	Dynamic econometric model
DSM	Dynamic systems model
EUE	Ecologically unequal exchange
FDI	Foreign direct investment
FISA	Framework for Integrated Sustainability Assessment
FLQ	Flegg's location quotient
GDP	Gross domestic product
GMRIO	Global multiregional input-output
GVC	Global value chain
IO	Input-output
JRC	Joint Research Centre of European Commission
LCA	Lifecycle analysis
MRIO	Multiregional input-output
MSIO	Multiscale input-output
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
RoE	Rest of the economy
RoW	Rest of the World
SAM	Social Accounting Matrix
SCGE	Spatial computable general equilibrium
SDG	Sustainable development goal
SNAC	Single national accounts coefficient
TBL	Triple Bottom Line
ToC	Theory of Change
VA	Value Added
WIOD	World input-output database
WIOT	World input-output table

1. INTRODUCTION

1.1 Background of the study

The global economy is now more connected than ever thorough multiple linkages in production chains as a result of international expansion of organizations (Gereffi & Lee, 2012; Johnson, 2018). This has made it possible for regions to specialize in certain parts of the value chain resulting in more efficient processes (Gereffi & Lee, 2012; Los et al., 2015). In turn, this has led to overall global economic growth (Iamsiraroj &Ulubaşoğlu, 2019) but also in inequal value distribution by region throughout the global value chains (Piñero et al., 2020; Stöllinger, 2021) and the growing need of expertise and reactivity in managing complex supply chains, well-demonstrated by the supply issues caused by the global COVID-19 pandemic.

Foreign investments are often seen as a way to achieve new markets, reduce productions costs and strengthen the competitive position of firms (Samir & Kumar, 2019). Therefore, a company might measure the results of set investment thorough monetary benefits, gained market share or divided risk, disregarding the evident effects that the venture has on the local and global economy, such as knowledge-transfer or rise in local employment (Iamsiraroj &Ulubaşoğlu, 2015). Capturing these "hidden" effects is important – maybe not in the view of the investing companies themselves – but in the eyes of the countries gaining or financially supporting the investments. This is when the analysis of global value chains is applied, described by Amador & Cabral (2016) as the "*key to understand the international creation and distribution of value, as well as the capacity of countries to prosper in an increasingly interdependent world*". Hence, nowadays companies, non-profit organizations and governments face the task of tracking and evaluating the global value flows in detail to optimize their processes and policy decisions in order to find the most suitable and cost-efficient investment options that maximize the value created with respect to triple bottom line impacts (Allen et al., 2017). To justify these decisions, different ways to beforehand evaluate the impacts caused by a prospective intervention has been developed, often referred as ex-ante impact analysis (Lecca et al., 2020) or effectiveness evaluation.

Effectiveness evaluation enables the capturing of wide range of sustainability impacts on determined scope (local, regional, global or organisation level). It begins with defining the current state and targets within a system (Clark et al., 2004) and ends in reflecting the outcomes and overall change on the predetermined goals. Quantitatively the approach relies heavily on available statistics about the flow of goods, value, emissions, and other embodiments as well as recognized economic theory. Hence, the approaches can be very transparent when public resources are used. The increased availability and quality of data in the last decades has enabled scholars to extend original methods of evaluating impacts to capture the wide-spread impacts on very detailed and international level, including the decomposition of multiplicative effect that happens when products cross borders multiple times (Arto et al., 2019; Koopman et al., 2014), *though Vassily Leontief laid the foundations for the process of demand-driven input-output analysis already in 1936, instituting the tracking of value embodied in goods* (Malik et al., 2019). Ever since, the refinement of methods to track value has been steadily progressing, and the frequent use of the methods derived from original method have started to steamroll in the 21st century as climate change, sustainability and circular economy have become global hot topics. In addition to traditional demand-driven input-output analysis these methods include dynamic economic modelling, general equilibrium theorems and variations of process analysis. However, for years the full utilization of these techniques has been held back by available computational capacity, which is another reason why they have not been utilized as extensively in the past as nowadays (Miller & Blair, 2009).

Computable general equilibrium models are used to evaluate the changes that a certain intervention such as investment has on the economy. In the models, real-world effects can be simulated by bringing change exogenously into a system, that is already embedded with economic theorems and initial data. (Bröcker et al., 2010) As these models can be either static or dynamic, they are excellent tools to evaluate the long-term impacts of investments and policies on a spatially restricted level (Montaud et al., 2020). However, in global context the amount of regional specific indicators, computational capacity and assumptions that would have to be made hinders the usability of the models.

Multiregional input-output (MRIO) models are static models constructed from systems of input-output tables that capture interregional effects of producing goods and services (Andrew et al., 2009). They allow the systematic tracking of value embedded within a value chain of produced commodity or service on both regional and global level, making them very useful tools for footprinting, investment and global value chain analyses. Major advantage of the MRIO-approach is that it can be extended with the introduction of satellite accounts or coefficient indicators which allow the tracking of impacts other than physical and monetary ones (Kitzes et al., 2013). In recent decade, the introduction of global MRIO databases has made global value chain analysis more straightforward, allowing individual practitioners to perform sensible analyses without years of experience in the field. However, as the building of the global databases is done by non-intergovernmental organizations (with the exception of OECD-tables) and requires harmonization and aggregation of data that evidently differs from national accounts, some official parties do not acknowledge the results based on MRIO analysis credible (Tukker et al., 2018). In spite of this, multiregional input-output models are one of the most prominent ways to assess the sustainability impacts embodied in global production networks that can be used to evaluate effectiveness of ventures beyond monetary indicators and divide responsibilities accordingly (Nabernegg et al., 2019). Hence, **GMRIO analysis is used as a base of many official reports and scientific reports, including this thesis.**

This was done in co-operation with a case company that is an expert-organization in the field of effectiveness evaluation, among other fields. The topic of global value chains and statistical cross-border impact assessment came from the needs of the case company, but the introduced empirical test case in the study is linked to a separate timely case known as European Union Recovery and Resilience Facility. Thus, the topic is further refined and extended by the writer's own interests from the company needs.

1.2 The case and company

This master's thesis was commissioned by Ramboll Finland Oy, regarding the evaluation of resource flows linked to foreign ventures. Within the thesis work, an existing statistical tool of the company was extended to cover global value chain linkages for future needs of Ramboll and adjusted for the purposes of the Facility evaluation displayed in figure 1.

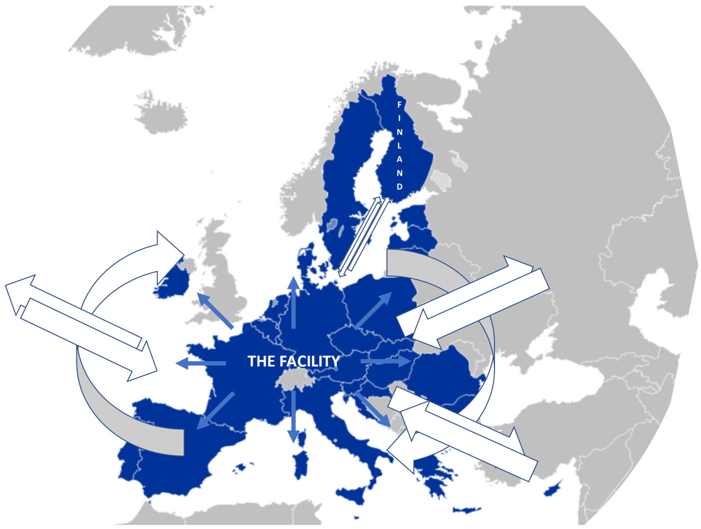

Figure 1. *Global value chain flows and the geographical coverage of the Facility*

This thesis describes the relevant available methods to quantitatively evaluate impacts of foreign investments. It covers the available databases for such evaluation on a global scope and glances on several “physical” models available for wide-scale impact evaluation created by internationally recognized organisations. This study also provides a simple representation of the statistical approach applied in modelling and presents both the structure of the constructed model and the summarized step-by-step process of constructing the model that was used to evaluate the downstream impacts of the Facility on one of the investing regions (Finland) with publicly accessible data.

1.3 Research questions and objectives

The purpose of this thesis is to bring forth overview of interregional effectiveness evaluation in the context of global value chains and to recognize the most prominent existing applications in the field of impact analysis covering sustainability impacts on an industrial level. Ramboll has extensive expertise in conducting effectiveness evaluation in Finland, and throughout its many projects it has identified the growing influence that value chain connections (design) have on final sustainability impacts on different regional levels. In fact, in many cases majority of sustainability impacts related to meeting local final demand originates overseas. Therefore, understanding the different factors that make-up that final impact is necessary in order to make justifiable decisions regarding sourcing, investments and policy options (Edens et al., 2015).

Ramboll has existing applications to capture the overall impacts of these connections on a national level but is interested in extending the current methods to capture these effects in more detail provide as high-quality analysis as possible for its clients. Therefore, besides creating understanding about the topic in global context the thesis is also concerned in combining the existing statistical approaches of the case company with up-to-date publicly available global resources. **Therefore, the main research question is:**

1. **How to evaluate interregional effectiveness of foreign investments?**

   This is supported by three additive research questions:

2. **What downstream sustainability impacts are traceable with global value chain analysis?**
3. **What influence does the design of value chains have on both the viability and sustainability of foreign investments?**
4. **How can an existing national IO model be developed into a global value chain and sustainability analysis tool *with publicly available statistics?***

A literature review is set to find out the answer to the first research question by exploring the current applications in the field around the globe. The additional research questions help assess the suitability of the practical solution based on initially answering the main research question. Simultaneously, they display which kinds of questions effectiveness evaluation can be used to answer in general. However, the thesis is limited in terms of fully validating the real-world impacts simulated with the model as the actual results from the Facility will realize in timespan of several years. Therefore, the validity of the model is based on the fact that it is built upon acknowledged economic theory, scientific literature and publicly available statistics as well as on a soft benchmark.

1.4 Thesis limitations and scope

This study was carried out as a constructive research where the literature review was conducted based on predetermined needs, findings of which led to further exploration of the theoretical grounds and publicly available resources of statistical modelling. A statistical framework and a model was constructed and initial test with the model was run before the final evaluation. These results were reflected on relevant findings in previous reports and literature to evaluate the potential and reliability of the model. Limitations and choices regarding the model and results was set due to available resources and time-limitations of the thesis. These limitations mainly refer to the Finland being the only country within the constructed model with subnational coverage. Rest of the model specific limitations are addressed in the chapter 5 and 7, overall limitations of the study follow.

This thesis is limited in finding ex-ante quantitative methods to effectiveness evaluation, hence it focuses on the methodologies used in literature. Therefore, the analysing of situations and results of previous studies is presented only scarcely and theoretical context is provided only for the methods utilized in construction. The evaluation is limited to number of distinct sustainability indicators extendable from publicly available data covering all three pillars of sustainability as the quantitative models used in impact assessments are not able to comprehensively capture all sustainability impacts at once (Allen et al., 2016) and vast amount of qualitive assumptions would have to be made in order to cover the entirety of sustainability matters.

In terms of the results, the scope of the study is limited to Finland in global value chains. This means that both the results presented and the optimal use of the empirical solution is limited to the assessment of Finnish impacts. However, the overall findings of the thesis, the modelling technique itself and the construction process of the model are universally applicable. The constructed model can also be used to address effectiveness in viewpoint of other countries as its base model is built on international statistics, though it would have to be adjusted considerably to cover other regions impacts in same detail as Finnish impacts.

1.5 Content of the research

The thesis composes of three parts – literature review and theoretical background of the study, research methodology and model construction, and the results, analysis and assessment of the method. The theoretical part begins with literature review that gives the reader basic understanding of the study field and the researcher justification to make choices regarding the practical implementation of the construction. First, the main concepts around global effectiveness evaluation are introduced with particular focus on sustainability matters and the international scope of the study. Second, the different approaches to statistical impact modelling are introduced and the potential applications and databases that can be used in global effectiveness evaluation are examined through examination of relevant case studies done in the field in recent years. After synthesizing the findings of the literature review to the context of Finland and research questions, an established impact analysis method is presented for further analysis. The second part of the theoretical background introduces the mathematical background, potential applications and challenges related to multiregional input-output analysis.

Fourth chapter discusses the methodological choices made in the study as well as the research process and presents the case of the study. Key matters being constructive approach to the research and the collection of data to the European Union Recovery and Resilience Facility scenario. This is followed by the introduction of the constructed model, a chapter which focuses on both the building process of the model and the usability of the statistical tool. An upfront view on the potential restrictions and updates to the model is also put forth in advance that is revisited in the critical assessment of the method later in the thesis.

Chapter six presents the results and the analysis of the study with a focus on internationally originating impacts of the Facility on the Finnish economy. It also presents the global value chain and sensitivity analyses that are further addressed in chapter seven. The seventh chapter addresses the analyses in question and reflects the results against an existing benchmark. Mainly though, it focuses on critical assessment of the method thorough the research questions of the thesis and considers the potential adjustments and upgrades to the constructed model. Finally, chapter eight concludes the study by evaluating the importance of the generated results and created construction thorough academic and practical contributions. Further research recommendations and practical implications are drawn based on the reflection, and final conclusions about the model operationality are given.

2. LITERATURE REVIEW

In this chapter, a literature review of effectiveness evaluation is conducted, with focus on ex-ante evaluation of impacts that shocks cause to an economy. Around the topic of impact evaluation and introduction of shocks to economy exists a lot of literature both on global and national level, but research centred on linking the global spill over effects from set shocks between geographically distant locations on a detailed level is quite sparse. The literature review is set to find out:

1. How is the topic researched, where and in which context?
2. What are the underlying methodologies and assumptions behind the models and frameworks used in the studies?
3. What publicly available models and databases suited for quantitative effectiveness evaluation exists and what are their limitations?
4. How are the findings applicable to assessing the spill over effects that foreign investments have on Finland?

The reviewed literature consists of both peer-reviewed scientific articles and working papers by expert governmental, administrative, and non-profit organizations in the field. Initially a variety of sources and approaches to evaluation was used in order to find diverse ways of addressing the phenomenon around the globe, but later the scope was more fixated on quantitative methods of assessing the impacts, mainly CGE and IO analysis as existing applications on analysing the problem at hand with these approaches were identified.

First, the literature review describes effectiveness evaluation and global value chain analysis in the context of the study and the main topics around them. After which, quantitative impact evaluation is addressed by uncovering static and dynamic modelling. Third, prominent existing models and databases are composed. Finally, the findings are synthesized to context of Finland and reflected on research questions of the thesis.

2.1 Concepts of interregional effectiveness evaluation

2.1.1 Evaluation of impacts

Effectiveness addresses achieving of goals set beforehand. Therefore, for the purpose of the study effectiveness is described as the power to produce desired results (Merriam-

Webster, n.d.). A typical way to assess effectiveness is analysis thorough impacts, which can be defined as the share of the total outcome that would happen due to the intervention in contrast to what would happen anyway (Clark et al., 2004). In essence it represents the result created from entering certain inputs into a system. Figure 2 represents a simple illustration of the logic.

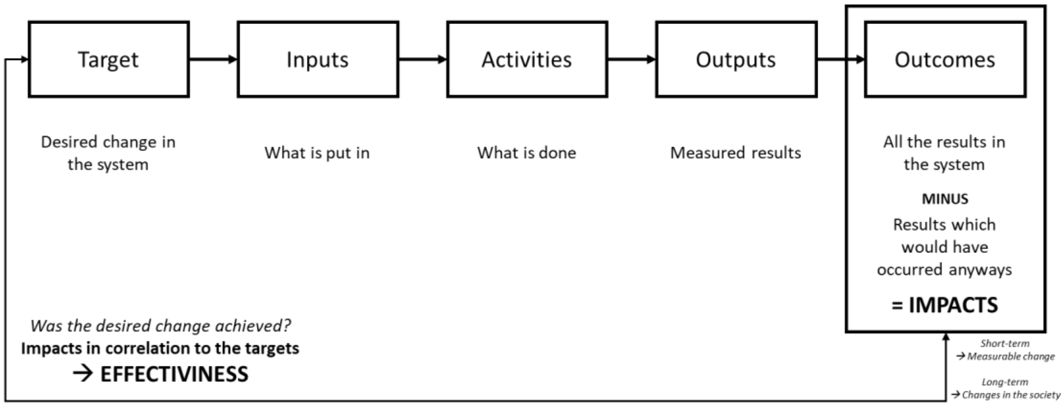

Figure 2. *Impact value chain (adapted and extended from Clark et al., 2004)*

Impacts can be evaluated beforehand "ex-ante" or afterwards "ex-post" (Lecca et al., 2020). Benefit of the ex-post analysis is that the output data is based on actual results, boosting the credibility of the analysis as the main error points reside in the assumptions made about the share of the results caused by the intervention, whereas ex-ante analysis is prone to mistakes already in the data selection and model building phase of set scenario. All though some could argue that this eliminates the need of considering the results that "would have occurred anyways" if the system was set just to measure impacts resulting from chosen inputs. The benefit of ex-ante assessment compared to ex-post is the fact that it is typically easier to make alterations in the planning phase of projects than afterwards, allowing the assessment of different pathways, options and trade-offs before the costs occur (Allen et al., 2017). Hence, the core idea of ex-ante evaluation – *a rough estimate to a relevant question beforehand is better than a perfect answer when it is too late* – **this study is focused on ex-ante evaluation of impacts**.

Impacts can be evaluated both in qualitatively and quantitatively. The strength of qualitative approach is its ability to evaluate intangible effects when numerical data is not available. A variety of approaches to qualitative impact analysis exists (Clark et al., 2004), but theory of change (ToC) based logics are often seen as the most prominent ones (Jackson, 2013). In ToC the process of change is displayed with causalities, underlying logics, and expected outcomes (Jackson, 2013) and it is used to build a path backwards from intended outcomes to the steps needed to achieve them. Theory of change is often used in when evaluating impacts of development projects as it is an inexpensive way to analyse complex problems in conjunction with other assessment methods among impact investors (Jackson, 2013), i.e., it serves as one of the bases to Finnfunds development effect assessment tool, DEAT (Finnfund, 2021). However, the downfall of qualitative assessments is that even though they are often based on expert interviews and legitimate theory, many assumptions have to be made in order to map the causalities – and using expert insights can become very time-consuming process (Collste et al., 2017). The benefit of quantitative effectiveness analysis is that in most cases both the inputs and outcomes can be displayed in numbers and the assumptions are mainly based on economic theory. Use of numerical data also enables the convenient analysis of different shocks, options and spill over effects (Lecca et al., 2020; Montaud et al. 2020) after a working model is created. As one of the main objectives of the study is to find universal ways of evaluating impacts and their international spill over effects, **this study is focuses on quantitative evaluation of impacts**.

The main weaknesses of numerical analysis are that the inputs of it are usually based on statistical data (input-output tables, material flow accounting, trade data and other) which are gathered, generated, and aggregated with different classifications, some terms are double-counted, and something is always lost or created when data is harmonized (Tukker et al., 2018). Recent academic literature has addressed these problems and demonstrated that different aggregation schemes of sectoral data can lead to significant differences in results (de Koning et al., 2015; Piñero et al., 2015; Steen Olsen et al., 2014), and that double-counting can lead to overestimations of global impacts up to 30% (Cabernard et al., 2019). Nonetheless, recent progress on accounting for double-counted terms is promising with existing theories being united and novel techniques created (Arto et al. 2019; Koopman et al., 2014) and challenges related to data aggregation, harmonization and handling can be seen to ease as more detailed statistics and quick ways to construct IO-tables are created (Malik et al., 2019).

Impacts can be evaluated on many levels depending on desired results, but **the main hypernyms used later in this study are economic, environmental, social and socioeconomic impacts**. Impact analysis is often based on singular parameter modelling such as money or materials but it is possible to analyse results on very detailed level thorough extensions as e.g., Rodríguez-Serrano et al. (2017) have analysed environmental impacts of photovoltaic (PV) project in as detail as biodiversity threats to specific classes and Collste et al. (2017) analysed impacts that a large PV project can have indirectly on life expectancy and education in Tanzania. As demonstrated, impact analyses are capable to capture all the triple bottom line effects (TBL) of ventures with a single model with use of official statistics, satellite accounting and indicators, making it powerful tool for sustainability assessments (addressed in 2.1.4). Rightfully so, sustainable development has accelerated the use and advancement of impact evaluation, especially IO analysis, as it has proven to be well suited method to analysis of material and carbon footprints, different policy options as well as potential investments – and often in more detail than traditional life cycle assessment (Liu & Wang, 2017).

2.1.2 Circulation of foreign investments impacts

Investments can be seen as ways to allocate money (e.g., making an acquirement) in order to create value in the future. Commonly the value is seen in the form of capital flows, but it can include wider set of indicators that either do or do not realize in monetary terms for the investor. For instance, it can be increase in market share and consumer awareness, that will most likely return to the investor as future cash flows or it can be an establishment of a youth centre that yields returns in more intangible terms such as increase in human well-being and reduction in youth crime. More often than not both types of investments have wider effects, both monetary and non-monetary, as the increased market share of a local company can boost the employment in the area or the youth centre might provide more business to the local maintenance firms.

Same logic applies in the context of foreign investments. For instance, a new production facility established in Ghana by a Finnish company most likely boosts the employment in the area, gives local firms access to foreign markets and provides positive knowledge transfer (Iamsiraroj &Ulubaşoğlu, 2015). In hand a boost can be seen in the operation of the company as it penetrates new markets and gains access to new commodities. Concurrently, a boost can be seen in in the Finnish economy thorough increased exports and domestic investment. (Sarin & Kumar, 2019). Similar wider socioeconomic effects are seen to other forms of international financing in addition to benefit seeking investments. These include foreign direct investments (FDI), loans, aids, developmental assistance and many other ways of supporting developing economies (Iamsiraroj &Ulubaşoğlu, 2019).

Traditionally, the motivation to do foreign (direct) investments is classified under four categories: market-, efficiency-, natural resource- and strategic asset-seeking (Meyer, 2015) which can be further classified as horizontal, vertical and technology-sourcing. However, many scholars have argued need for more singular terms to better capture the distinct purposes of different investments (Sarin & Kumar, 2019). Regardless of the classification, the approaches highlight the clear efforts to gain something as the investor (Meyer, 2015). Though, the approaches disregard the effects that investments have on host economy by definition, they do highlight the benefits that host nations provide to investors in order to get the investments within the region as the benefits to the host country are evident. In addition to home and host country benefits, foreign investments are generally seen to have a positive effect globally, though this does not realize in every case (Iamsiraroj &Ulubaşoğlu, 2019).

Capturing the global effects of investments is a challenging task that has gained more awareness in recent years. However, impacts of single investments for a certain agent, a company for instance, are most often captured solely with wide set of financial analyses such as cost-benefit-analyses or other ways to evaluate returns on assets, disregarding the circulating- and wider-economic impacts (Bröcker et al., 2010). This is not peculiar as in most cases these benefits are very minute for the agent and the analysis is laborious. However, capturing these impacts is very important in the big picture which is why it is either recommended or required to do so in many parts of the world. These impacts involve factors beyond monetary ones like employment, emissions and material flows.

This study is focused on global value chains and capturing the broad effects of foreign investments on an international scope. Multitude of ways to capture these impacts have evolved around the concept of global value chain analysis, some of the most prominent ones being computable general equilibrium, multiregional input-output and lifecycle analyses (Nabernegg et al., 2019). Consequently, the challenge of evaluating impacts has stretched from the evaluation itself to choosing the right method for the evaluation.

2.1.3 Flows in global value chains

Global value chains (GVC) capture the geographical fragmentation of supply chains (Gereffi & Lee, 2012). Ultimately, global value chains are an extension to original concept of value chains which capture all the activities needed to deliver final goods to end users (inbound logistics, production, marketing etc). Concept of global value chains has gained popularity since the beginning of the 21st century due to international expansion of production stages (Gereffi & Lee, 2012; Johnson, 2018) as labour-intensive tasks were offshored and exports were mounting as a result of reduced transportation, communication and trade costs (Amador & Cabral 2016; Los et al., 2015). A simple illustration of internationally fragmented value chain can be seen in figure 3.

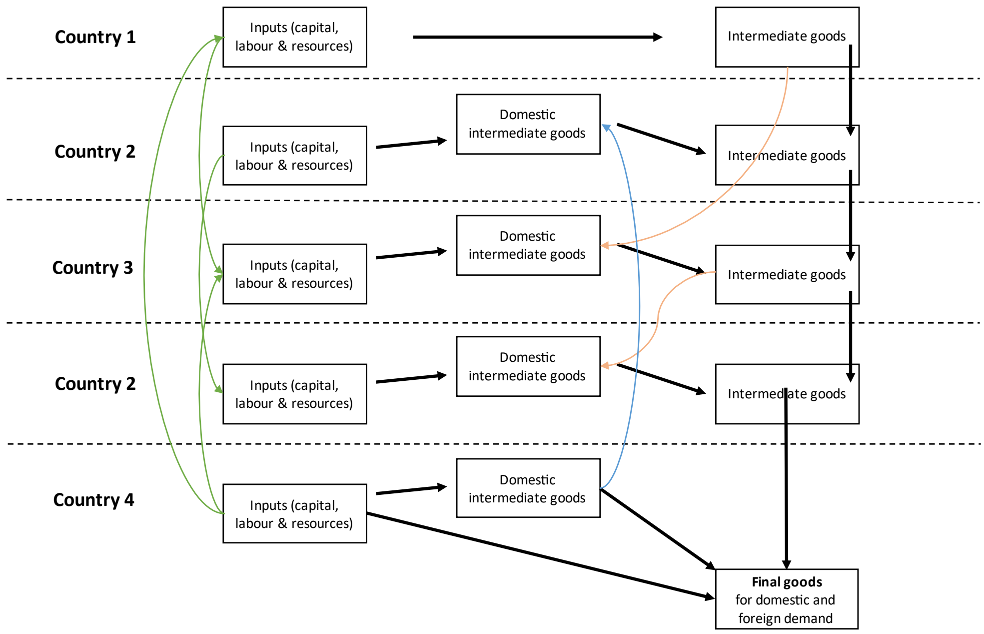

Figure 3. *Internationally fragmented value chain for producing a single type of final goods (adapted and extended from Los et al., 2015)*

As inputs to produce final goods often originate from multiple locations around the globe (Gereffi & Lee, 2012) specific ways to account for intermediate goods are needed. Looking at just national and trade statistics does not work when evaluating impacts in context of global value chains as it will lead into accounting for the intermediate products multiple times if the product crosses borders more than once as figure 3 demonstrates (Gunnella et al., 2017). Benefit of practitioners, double-counting has been taken into account in up-to-date global input-output (IO) tables that capture the interconnectivities of global value chains. These interlinkages are integral and enable the full capturing of impacts when analysing effects that a certain venture or trade policy in location A has on location B or on the overall foreign sector effects of a location (Los et al., 2015; Portella-Carbó, 2016).

Activities within value chains can be grouped into upstream and downstream activities, where upstream activities traditionally cover the input side of the value chain and downstream activities locate to the side of final demand (Mudambi, 2008). *In value-added (VA) accounting, the downstream participation of a sector or a country in global value chains can be measured as the value added that is embedded in foreign inputs that are used in the export production. In turn, upstream participation can be measured as the value-added in intermediate products that are exported to a trade partner, reprocessed and further exported by the trade partner.* To address the downstream side of the global value chain activities in more simple manner, it can be seen as the side of industries that purchase inputs from other sectors to produce final goods ergo it resides on the side of final users. (Gunnela et al., 2017) Merging the views of Mudambi (2008) and Gunnella et al.

(2017) serves as the basis of evaluating downstream effectiveness in the case of this study as the impacts and spill overs from introduced shocks are tracked within a model driven by final demand with intersectoral GVC linkages based on global trade data**.** With this interpretation activities such as investments, use of sold products and end-of-life treatment can be seen as downstream activities. **The main focus of this study is on downstream effectiveness** but in context of global value chains upstream activities have a clear influence on the downstream side and vice versa (Acemoglu et al., 2016).

2.1.4 Indicators capturing sustainability impacts

Sustainable development has become part of everyday business as the "cornerstone of the future" and many policymakers have made it major part of their strategies on both governmental and organizational level. This in turn has caused a rapid boost on the amount and type of impact analyses conducted. More recently the introduction of United Nations (UN) sustainable development goals (SDGs) has sparked many academics to adapt their existing models to cover these (Allen et al., 2016; 2017; Collste et al., 2017).

Nowadays, covering sustainability is at the heart of many impact analyses as many frameworks allow the convenient analysis of triple bottom line impacts, usually within one model. As the analysis techniques can cover the material, emission and monetary flows caused by disruptions, impact analyses of ventures are able to capture the core effects of sustainable development as described by Brudtland's commission (1987):

> *"Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

As there are hundreds of individual descriptions of sustainability, this thesis adopts the official description presented above on the matter. Generally, sustainability is covered thorough three main dimensions – economic, environmental and social dimension – often referred as either the three pillars or principles of sustainability. **Economic** dimension denotes that businesses need to maintain an operating profit with responsible and effective use of resources. **Environmental** dimension covers aims to reduce the global carbon use and to reduce the deterioration of natural resources such as fisheries, forests and other land and water resources (Ostrom, 2009). **Social** dimension promotes the efforts for social wellbeing, covering topics such as employment, gender equality and the standard of living. To cumulate sustainability knowledge common frameworks need to be created and adopted (Ostrom, 2009) and though many frameworks covering sustainability endeavours have been created (European Commission, 2021; Rodríguez-Serrano et al., 2017; United Nations, 2021), they are not necessarily widely adopted. These frameworks often capture the main dimensions of sustainability by building goals, targets and indicators around the sustainability dimensions with targets focusing on distinct matters that can be measured and evaluated with the use of various quantitative indicators.

The most common indicator framework of the 21st century covering sustainability impacts is the United Nations Sustainable Development Goals that were adopted by all UN members in 2015 as a part of the 2030 Agenda for sustainable development. Created to ensure that the planet prospers now and in future, the goals include 169 targets, and a wide range of indicators that unite sustainability endeavours on local, regional and global level. According to the United Nations (2021) the goals are just but demanding, and recently seen new struggles in form of a global pandemic, therefore ways to evaluate the best options to tackle these challenges beforehand are now more important than ever. As many of the SDG indicators are evaluated using publicly available databases and by creating common indicators and satellite accounts, effectiveness evaluation based on official quantitative statistics is very notable option to appraise the potential sustainability impacts of actions before their implementation that the United Nations emphasize. Table 1 demonstrates a sustainability framework by categorizing the UN's sustainable development goals and the indicators measuring the progress towards set goals.

Table 1. *UN sustainable development goals (based on United Nations, 2021)*

Goal number	Sustainable development goal	Number of indicators
1	End poverty in all its forms everywhere	14
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	13
3	Ensure healthy lives and promote well-being for all at all ages	28
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	12
5	Achieve gender equality and empower all women and girls	14
6	Ensure availability and sustainable management of water and sanitation for all	11
7	Ensure access to affordable, reliable, sustainable and modern energy for all	6
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	16

9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	12
10	Reduce inequality within and among countries	14
11	Make cities and human settlements inclusive, safe, resilient and sustainable	14
12	Ensure sustainable consumption and production patterns	13
13	Take urgent action to combat climate change and its impacts	8
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	10
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	14
16	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	24
17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	24

Table 1 captures the essence of the global indicator framework that consists of 247 official SDG indicators, 231 of which are unique (United Nations, 2021). The introduced goals and indicators are globally adaptable although some of the indicators and targets are more suitable for certain areas. Hence, many other targets and indicators are set for specific regions by governments and large governmental bodies such as the European Union in spite of the United Nations goals being adopted by all of its member states. Another example of sustainability framework is the EU's adaptation of the UN's Sustainable Development Goals. The framework measures European Union member countries progress towards SDGs in EU context with only 100 quantitative indicators (Eurostat, 2021). These indicators are demonstrated in table 2 with a singular quantitative indicator example for each of the sustainable development goals in Eurostat's framework.

Table 2. *Take of EU's SDG indicator framework (based on Eurostat, 2021)*

Goal	Statistical indicator	Indicator name
1	% of population aged less than 60 and thousand persons	In work at-risk-of-poverty rate
2	million EUR and EUR per capita (current prices)	Government support to agricultural research and development

3	% of population aged 16 or over: i. Total, ii. Males, iii. Females	Share of people with good or very good perceived health
4	% of persons aged 25-64	Share of adults aged 16-74 having at least basic digital skills
5	% of average gross hourly earnings of men	Gender pay gap in unadjusted form
6	mg NO3 per litre	Nitrate in groundwater
7	kg of oil equivalent	Final energy consumption in households per capita
8	Chain linked volumes (2010) in EUR and % change on previous year	Real GDP per capita
9	total number and number per million inhabitants	Patent applications to the European Patent Office (EPO)
10	% of income	Income share of the bottom 40 % of the population
11	square meters per capita	Settlement area per capita
12	% of total material use	Circular material use rate
13	index 2000 = 100	Greenhouse gas emissions intensity of energy consumption
14	pH value	Mean ocean acidity
15	km2 and terrestrial protected area (%)	Surface of terrestrial sites designated under Natura 2000
16	million EUR and EUR per capita (current prices)	General government total expenditure on law courts
17	% of GDP and million EUR (current prices)	General government gross debt

Despite leaning heavily on United Nations goals, the sole purpose of the European Union's indicators is not to address SDGs but also to provide useful information on other endeavours towards sustainability. This is why these indicators like many others get adjusted over time and are open to reviews and suggestions. (Eurostat, 2021) As there are plethora of statistical indicators, the tables introduced are limited to 17 examples, *for detailed and downloadable descriptions of all of the indicators one should consult UN-Stat, Eurostat or DIHR*. Regardless of the limitations, table 2 demonstrates that some of the indicators can be clearly prolonged from official statistics (see e.g. goal 2, 9 and 16) whereas some of the indicators need more elaborate analysis – especially in the process of generating reliable statistics (Kussul et al., 2020). This need of analysis is further highlighted by the fact that SDG target 11.c "*Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials*" does not have a clear indicator anymore for itself (United Nations, 2021).

Due to great part of these indicators being measured with publicly available statistical data, quantitative effectiveness evaluation can be sensibly used to evaluate the attractiveness of actions towards achieving sustainable development whether it is thorough SDGs or other indicators by utilizing existing data, models, theorems and timeseries. Tables 1 and 2 in conjunction demonstrate that many of these indicators are a combination of multiple sustainability dimensions when examined at the level of indicators. This allows the generation of tied coefficients that is very common practise in sustainable value chain modelling as many social and environmental indicators can be created based on economic changes and development as long as base statistics for these parameters exist. Running with the idea, by further connecting all the indicators to one and other with magnitude of statistics, trade links, and coefficients it would be possible – in theory – to create a global model that covers the entirety of the SDGs and global value chains. However, as Allen et al. (2016) among others state that it is improbable that a single modelling framework can analyse all the impacts on SDG targets and indicators to a sufficient extent, **in this thesis indicators related to climate change, natural resources and socio-economic development are mainly addressed**.

2.1.5 Approaches addressing responsibility over sustainability

Sustainability is a global dilemma and the importance of sustainable development is undisputed, challenges do arise when responsibilities over impacts are cogitated. **With responsibility this thesis refers to certain parties being accountable for the change in the system (e.g., emissions, material use and social improvement)** which is important factor when considering fulfilling ones sustainability targets and promises, as it can serve as a basis for carrot and stick procedures for different regions. There have been many agreements to address sustainability, more so climate change, such as the Kyoto protocol and Paris agreement in which the environmental responsibilities are measured and allocated based on set criteria. The most obvious problem with the agreements is the fact that not every country is part of them. This in succession cultivates the problem of carbon responsibility because some responsibility approaches allocate emissions solely based on location of production and extraction. This in turn, amplifies the negative effect related to responsibility allocation as Malik et al. (2016) state that considering direct emissions alone (as in Kyoto protocol) makes carbon mitigation effects less effective due to the neglection of outsourced emissions. In reality, the challenge of allocating responsibilities goes way beyond this, demonstrated by Wang & Qe (2020) who analyse the final use of Chinas much-criticized coal consumption with different emission responsibility allocation approaches, and show that much of it is ultimately caused by final demand in Western economies. This begs the question, what is the optimal way to allocate environmental responsibilities fairly?

Three main ways to allocate full environmental responsibilities have been introduced in literature – production-based, consumption-based and income-based responsibility approach. On occasion, these full responsibility approaches are further modified to shared-responsibility approaches that divide accountability more equally based on fractions of involvement within global supply chains. (Piñero et al., 2019) Piñero et al. (2019) describe the full responsibility allocation methods as follows.

Production-based responsibility accounts for all the environmental pressures within firm's domain or country's territory caused by economic processes. Therefore, it does not allocate the pressures related to traded products and focuses heavily on material extraction activities. **Consumption-based responsibility** allocates all the environmental pressures to the final demand that are generated in the whole supply chain in order to produce the final goods. Therefore, on a national level the total material footprint is measured as domestically extracted raw materials (RM) plus RM embodied in imports less RM embodied in exports, needed to satisfy the final demand. **Income-based responsibility** allocates the responsibility to the owners of the factors of production based on income generated from payments. Consequently, the responsibility is rolled to the suppliers as they enable the environmental pressure by selling the production inputs.

Additional shared responsibility approaches exist besides the three full responsibility approach variants, namely beneficiary-based, distance-based and value-added based responsibilities. Last of which allocates the environmental pressures to all participants based on their shares in supply chain wide value creation. Contrary to the original shared responsibility approaches, it does not allocate any pressure based on the final consumers. (Piñero et al., 2019) This makes it very attractive option for wide-scale sustainability responsibility schemes. However, the approach does not account for technological differences between actors comprehensively e.g., it ignores the benefit of efficiency as base for extracting more value from inputs which deteriorates its attractiveness (Piñero et al., 2019).

All of the responsibility approaches introduced have their own shortfalls. The main problem in majority of approaches besides consumption-based accounting (CBA) being developed countries, where most of the final demand resides, outsourcing their energy-intensive production to the developed countries with weak environmental policies and importing the final products back as part of the global supply chains (Essandoh et al., 2020). This averts their responsibility but increases the total amount of globally harmful environmental impacts. The major con of the scheme is that most of the developed countries have higher technological capabilities than developing ones and would therefore be able to produce the goods more energy-efficiently but choose to outsource the activities based on approach chosen to allocate the responsibility. Fortunately, problems over responsibility approaches have been highlighted recently as production-based approach has been widely used in global climate change agreements such as UNFCC and Kyoto protocol with less than perfect success (Mi et al., 2016) – though no single approach is yet to be proclaimed as superior by international agencies.

The issue of outsourcing energy-intensive and extractive activities into developing countries is well covered in the literature (Essandoh et al., 2020; Mudambi, 2008; Piñero et al. 2020; Stöllinger 2021). One of main theories behind the criticism for the phenomenon is Ecologically Unequal Exchange, theory which emphasises that free trade creates winners and losers as rich countries are specialised high value manufacturing and service activities whereas developing countries specialize in low value tasks that have high social and environmental impacts such as extractive tasks (Piñero et al., 2020). Another view on the matter, based on the same general thought is the classification of countries as either headquarter or factory economies which emphasizes the unequal distribution of activities in global value chains by displaying that both upstream and downstream high value-added tasks are located in the most developed countries (Stöllinger, 2021). Despite the fact that there are clear issues related to the use of responsibility approaches, the overall phenomenon is not straightforward. Responsibility should not only be looked at level of nations as Malik et al. (2016) and Piñero et al. (2020) have illustrated that countries classified as developing can have areas within them that are very advanced making the locations net-importers of goods and vice versa there are areas in developed countries that can serve as both net-exporters or -importers depending on comparisons.

A vast amount of literature demonstrates that different responsibility allocation approaches drastically affect the final results on both city level (Mi et al., 2016) and national level (Piñero et al., 2019). It does not however provide an ultimate answer to choosing ultimate responsibility allocation method. Even though not being perfect approach by any means, **consumption-based approach is the responsibility approach that is mostly**

covered in later analysis in this study. The main reasoning behind this is its usability in analyses based on IO-data and ability to capture wider-economic impacts of ventures have based on the global value chain wide coverage of the approach. It has also been accepted by increasing number of researchers in the field (Mi et al., 2016) and stated to be the more equitable accounting solution (Wang & Qe, 2020) to impact analysis.

2.2 Statistical modelling in global value chain and sustainability analysis

2.2.1 Established impact modelling approaches

Under the chapter impact modelling refers to quantifying of the effects that a disruption has on a system. The set system can have a limited domain, or it can represent the whole world. Disruption, later shock, can consist of any defined activities to a system that effects its balance i.e., it can be a venture, investment, policy change or natural disaster. A shock to a single unit (firm, sector, region, country) can have a great impact on the macroeconomy as it either reduces or increases the output of the set unit and all others that are connected to it through a network of input-output linkages (Acemoglu et al., 2016). These shocks can be either domestic or foreign based on the origin (Lee, 2019) but in today's global economy domestic shocks tend to have impacts outside of the country of origin. Figure 4 illustrates the transmission of shocks with numbers denoting specific industries, IOs their linkages, EX exports, IM imports and C countries, lines bilateral linkages and dots further linkages.

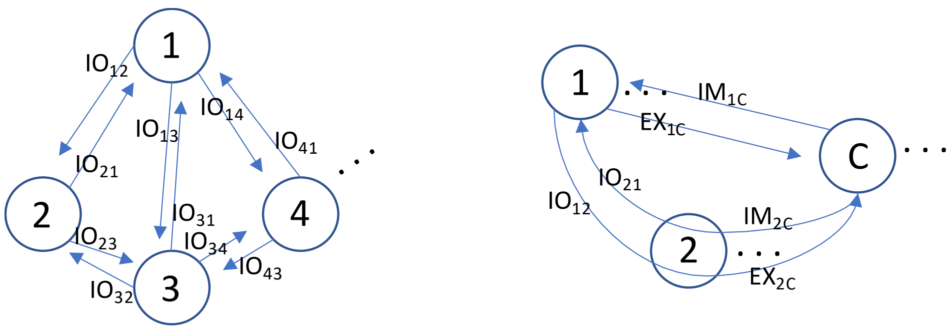

Figure 4. *A representation of domestic industry (left) and external country (right) growth shock transmission (adapted from Lee, 2019).*

A variety of ways to model the impacts of shocks beforehand exist, that can be classified in many ways. According to Allen et al., (2017) scenario modelling approaches include input-output analyses, top-down systems dynamics models, top-down macroeconomic computable general equilibrium (CGE) models, macro-econometric models, bottom-up optimization models, bottom-up simulation models, bottom-up multiagent models and hybrid models. Further modelling approaches include agent-based modelling and stock-flow consistent modelling (Nabernegg et al., 2019). Whilst it is common for the models to utilize existing economic theory and statistical data, they differ in multiple points from one and other. For instance, the latter modelling approaches presented tend to ignore complexities of international trade that are crucial in consumption-based accounting (Nabernegg et al., 2019) and trade data alone does not capture the wider impacts in as detail as IO-based analysis (Liu & Wang, 2017). Moving forth, **this study focuses on statistical analysis methods based on IO-data**. These approaches can be compressed into broader categories, namely static demand-driven input-output models, dynamic macroeconomic input-output models and computable general equilibrium models (Wiebe et al., 2018). However, various alternative formulations and hybrids of these models exist, blending elements of different types of models (Allen et al., 2017; Wiebe et al., 2018) that can be referred to as the models itself or combination of these (e.g., IO-LCA, CGE-MRIO). **In this study the classifications are further compressed into static and dynamic modelling approaches** for the sake of simplicity as the core methodologies behind models itself are examined in more detail. With this analogy, a division of different methods recognized (Allen et al., 2016; 2017, Appendix A) and studied during the research process is displayed in figure 5.

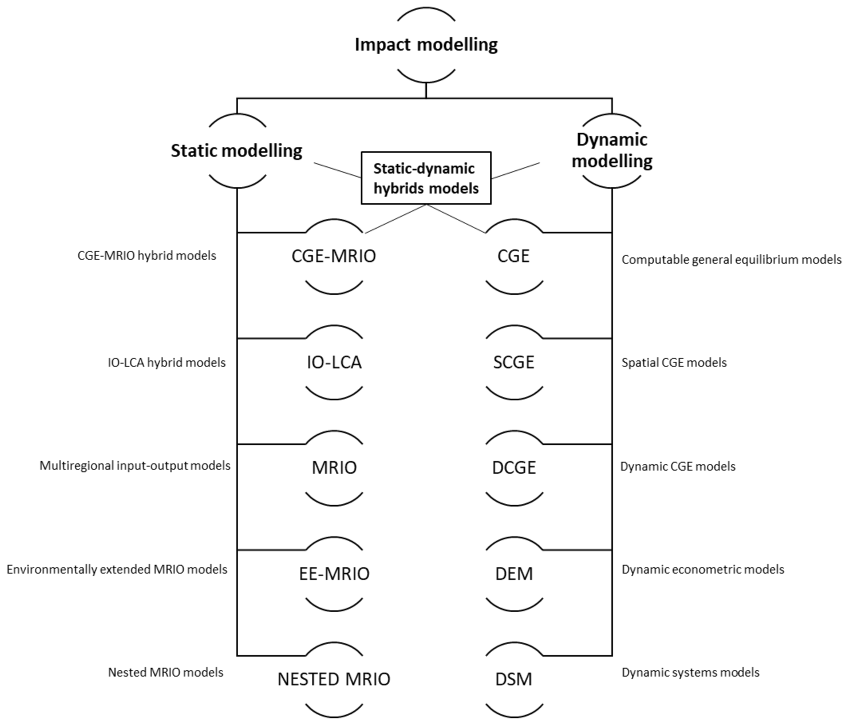

Figure 5. *Synthesis of different modelling approaches*

Static models capture the system as an equilibrium. Introducing a shock such as new policy or demand into the system disrupts the equilibrium. By bringing the system back into equilibrium the impacts (changes in the system) can be evaluated by comparing it to the initial condition of the system or business as usual (BAU) scenario. Therefore, it ultimately provides a snapshot of different states that the system is at but does not capture the time-inducing changes which is its main difference to dynamic models. However, it is possible to capture the time-element to a certain extent with static models, by introducing the shocks and their impacts sequentially in both IO- (Malik et al. 2014) and CGE-analyses.

In **CGE** modelling the change brought into the system exogenously disrupts the equilibrium and the system is brought into new equilibrium with economic functions embedded in the models (Bröcker et al., 2010). It allows the simulation of wide spread of shocks to the economy (Montaud et al., 2019), and it can be either static or dynamic at its nature. **Input-output** tables themselves are barely accounting systems (Wiebe et al., 2018). They capture the interconnectivity of sectors, regions and countries by linking the different inputs needed to produce outputs and value chains related together depending on the geographical broadness of the system. Hence, they serve as a strong base to create models that capture the widespread impacts of change on (Faturay et al., 2020). This is usually done with demand-driven logics based on Leontief's original input-output model but can be extended with use of more economic functions (Simola, 2019) to slightly mimic the CGE based models. Supply-driven IO model does also exist, most commonly known as the Ghosh models, but they have not gained strong foothold in the field. Other variations of demand driven input-output modelling includes adding of new sector to the existing IO-table to which balancing approaches exist, most common of which is RAS-method and its variations (Malik et al., 2014).

Basic principles of dynamic IO-based models are very similar to those of static ones and differ mainly from them by being reactive and clearly capturing the time-element. As they are able to capture the accumulating effects and react to the changes already during the simulation, they are seen as the suitable tool for long-term impact analysis (Mbanda & Chitiga-Mabugu 2017; Sangare & Maisonnave, 2018). One of the more common methods for the purpose is dynamic CGE modelling where the models are simulated with wide range of shocks based on numeric data (Montaud et al., 2020). As these models consist of numerous equations and variables, covering them in detail is not practical in the scope of this study. Therefore, readers should consult and Decaluwé et al. (2013), Montaud et al. (2020) and Lecca et al. (2018) for more detailed descriptions about the common and specific functions used in majority of CGE models. Henceforth, only the main assumptions made in studies using CGE models differing the models from each other are portrayed.

Both CGE and MRIO (multiregional input-output) models require various choices about the used data, the sectoral aggregation within the models and the magnitude of shocks introduced to the models. And as the methodology behind models has a large impact on the final results – though the inputs are usually based on official statistics or studies – creating and running the models does require operator consideration. Therefore, a major focus of the rest of the chapter is in identifying the differences in core choices, methodologies and data sources applied by different researchers in the field. This is done by describing the model building process in each case, displayed in table 3. The synthesis of the core ideas and the universal applicability of models will be further discussed in chapter 2.2.4.

Different modelling approaches are widely applied in literature, therefore a set of criteria for choosing studies for scrutinization was applied based on predetermined needs of this study. These included the ex-ante approach to modelling, introduction of predetermined shocks to a real economy and the examination of wider economic impacts or spill overs effects. The criteria was loosened if a study that had strong and unique methodological insights on impact modelling.

Table 3. *Models to evaluate wider economic impacts studied in literature*

Model used	Model type	Modelled case	Authors
EE-MRIO	Static	Energy investment	Faturay et al., 2020
EE-MRIO with FISA framework	Static	Energy investment	Rodríguez-Serrano et al., 2017
CGE	Dynamic	Public infrastructure investment	Mbanda & Chitiga-Magubu, 2017
Hybrid IO-LCA	Static	Establishment of new industry	Malik et al., 2014
SCGE	Dynamic	Investment policy	Lecca et al., 2020
Dynamic systems model	Dynamic	Energy investment policy	Collste et al., 2017
CGE	Dynamic	Infrastructure investment policy	Montaud et al., 2020
SCGE	Static	Infrastructure investment policy	Bröcker et al., 2010
Nested EE-MRIO	Static	Emission reduction project	Chen et al., 2016
Hybrid IO-LCA	Static	New production into a country	Malik et al., 2016

IO-framework	Static	Demand, supply and tariff shocks to Chinese economy	Simola, 2019
CGE	Dynamic	Reinvestment policy	Sangare & Maissonave, 2018
CGE-MRIO	Static	Policy changes	Nabernegg et al., 2019

Table 3 presents the selected studies to the scrutinization that met the predetermined criteria. An extended version of the table can be found in Appendix A that captures the main findings addressed later in chapters 2.2.2, 2.2.3 and 2.2.4 within one table. Supporting information from other studies has been brought forward when they have had strong influence on the presented studies or been otherwise relevant in capturing the overall essence of the topic.

2.2.2 Static modelling in impact studies

Faturaya et al. (2020) create a new US-MRIO (Uslab) model with help of Industrial Ecoloby lab (IELab) to evaluate the national economic impacts caused by a possible wind-energy projects within 10 states of the United States of America. The initial tables for the model are constructed from national supply-use tables of United States and further disaggregated with Fleggs location quotient (FLQ). Eventually the tables are further adjusted with state level data on imports, exports, GDP and private consumption expenditure and finally aggregated into 20 sectors due to data constraints. However, the model is able to report the impacts on much more disaggregated level due to its use of NAICS codes. The economic impacts are calculated by bringing demand data from Jobs and Economic Development Impacts (JEDI) wind model by the National Renewable Energy Laboratory (NREL) to the model and final impacts are captured as a snapshot that is compared to baseline year of 2017. The shocks are introduced to the gross fixed capital formation and others to rest of final demand (from JEDI data on state level) in the MRIO model, and the spill over effects to other states are calculated with the US-MRIO model. **Though the model only represents the US economy it is able to capture international impacts of the investment by including import and export activities in the intermediate matrix**. Therefore, it only directly captures the global value chain links of goods entering and leaving the economy. The method behind creating final economic impacts within the model is the Leontief's demand-driven logic, further extended to cover energy indicators with coefficient matrix, calculated from spatial energy footprint based on a US government survey data. Therefore, the model by Faturaya et al. (2020) is in fact an EE-MRIO. Despite the model being a good representation of US economy, it lacks flexibility to capture the long-term impacts as well as the distinct impacts beyond borders of the US.

Rodríguez-Serrano et al. (2017) use the “Framework for Integrated Sustainability Assessment” (FISA) to measure sustainability impacts that a large solar thermal energy (STE) project has within Mexico and internationally via the global value chain. The FISA-framework is based on connecting the demand-driven MRIOTs impacts to a wide range of individual indicators to capture the sustainability impacts and the changes. **The simplicity of the framework lies in the extensions (economic, environmental, social) that are connected onto MRIO model by using multiplying vectors of the corresponding indicator unit per monetary unit in the model**, following the same methodology as in Futuraya et al. (2020). The baseline database to the constructed MRIO model is world input-output database (WIOD) to which the social indicators are assigned from social hotspot database (SDHB) based on working hours results that can be captured with official WIOD extensions. Environmental extension data not covered by the satellite accounts of WIOD such as biodiversity data is clustered to the framework from Eora data. Regarding the location and technical configuration of the project for the shock scenario experts were consulted (namely PSA & ESTELA) and information from previous studies and benchmarks was applied. Economic impacts of the STE projects are modelled with these estimates and other sustainability captured with corresponding satellite accounts. As the share of international resources needed for the project was taken into consideration in the scenario formation and WIOD is used as a baseline, the model is able to clearly capture the impacts on both Mexico and to other countries within the global value chains. The main perk of the model is its simplicity and ability to capture several sustainability impacts within one model by using relevant satellite accounts. However, the replicability of the total analysis is hindered by the need of vast amount of detailed data about the project requirements in order to form credible scenario.

Malik et al. (2014) create an analytical and numerical approach to re-balancing IO-tables in order to evaluate the impacts that a new biorefining industry has on Australian economy. In this case technological change is modelled, and the underlying thought behind this in keeping the main production recipe of economy same when introducing new industries into the economy that would be disturbed if a traditional RAS-based balancing method was applied. The changes in the economy are brought into Australian national IO-tables based on benchmark scenario from Brazil in correct shares **– the new industry needs certain new inputs and takes market share from existing sectors** – and result in unbalanced Australian IO-table. In order to model the changes, the table is balanced analytically with the use of shares determined earlier and a coefficient matrix, and numerically by using RAS-type approach that runs computations to the model. The simplified process of running computing loops to achieve balanced table follows; *1) computing the total demand and supply of the products, 2) scaling the supply of products down, 3) computing total industry inputs followed by outputs, 4) scale the total industry outputs and returns to the start until the table is balanced*. By only scaling the columns of augmented IO-matrix the method is able to keep the original production structure of all sectors intact. As the IO-tables are balanced, the wider impacts can be captured by using satellite accounts similarly to Futuraya et al. (2020) and Rodríguez-Serrano et al. (2017). Since the data to model the changes (shocks) to the Australian input-output tables (from Eora MRIO) is brought from Brazilian benchmark, the universal replication of the method is reliant on similar benchmark data, unless assumptions based on expert insights are made. Benefit of the introduced RAS-based balancing method with IO model is that it can be used to somewhat mimic time-bound impacts that dynamic models have by applying LCA and production chronologies and running the changes with RAS sequentially.

Chen et al. (2016) assess the interconnectivity of different cities carbon footprints with a multi-scale nested transnational MRIO approach. They construct globally closed MRIOT with 25 sectors covering 5 large Chinese and Australian cities by following the guidelines of previous studies and by allocating international import and overseas exports to city-scale according to shares in the local intermediate use and supply. This connection implicitly assumes the proportionality of international inputs to local inputs and exports to local supplies. Constructing the nested intercity MRIO relies heavily on use of SUTs created previously for Chinese provinces and national statistics, moulding of Australian city tables with IELab using FLQ and using modified RAS to balance the tables, and Eora for the rest of the regions data. Extending the model to demonstrate city-carbon maps is done by modelling impacts with Leontief's demand-pull method. Concrete impact evaluation is done by introducing technological change in the model from which the downstream reductions in other regions are seen as the model connects resource flow between cities. Despite procedure for introducing impacts being simple it captures the effects circulating via global value chains well. The connection of cities itself allows for more focused evaluation of policies and investments as they can be then targeted nationally and internationally to locations that have a strong impact on wanted regions. However, **creating a similar model is a challenging task due to data constraints as only a number of publicly available city level input-output tables exists and detailed data of intra-regional trade is also seldom shared**.

Malik et al. (2016) evaluate the triple bottom line impacts of new cellulose-refining industry with a hybrid LCA-MRIO analysis. Utilizing Australian MRIO tables from IELab with satellite accounts based on Australian official data (ABS, BREE & DCCEE) the sustainability impacts are evaluated at very disaggregated level of regions and sectors (13 352 x 13 187). By populating the MRIOT with additional rows and columns based on process data on the expected changes, direct and indirect TBL impacts are calculated using an augmented table. For the augmentation process production recipes of operating inputs to carry out the forestry operations are gathered from previous studies. These are broken down into mentioned operating inputs with a transport model, and further reinforced with IO-data and external data from NREL. The evaluation of set impacts is measured with use of satellite accounts and Leontief's method as in the studies previously. Different scenarios are evaluated by decomposing the **final demand vector to pieces, on which set scenarios are introduced by implementing a nonzero elements that represent the change.** The losses in other industries that utilize same biomass as biofuel production are evaluated by introducing a demand shock to the system (more precisely on the total output of biomass) to capture the loss in employment and the economic stimulus. The analysis enables the evaluation of reminiscent scenarios in a consistent framework that combines the strengths of both IO modelling and LCA as the detailed process data for scenarios leans on LCA and the impact modelling on IO analysis that captures both the direct and indirect impacts within value chains and removes truncation error. However, the combined-analysis does not capture global effects in detail and requires burdensome gathering of process data.

Simola (2019) evaluates the impacts that shocks introduced to the Chinese economy have globally by using IO analysis extended with distinguished economic functions. These shocks are examined with global MRIO model (GMRIO) built on publicly available WIOD database, similar to Rodríguez-Serrano et al. (2017), that covers a rest of the world region and 43 individual countries including China. Methodologically Simola's model development mostly follows Vandenbussche et al. (2019) who built and economically-extended IO-framework to examine the impacts of tariff increases following Brexit. Besides standard demand-driven IO analysis Simola utilizes a set of economic functions in the analysis by implementing gravity-type approach, augmenting trade in value added as in earlier literature and implementing multisector production approach presented in Vandenbussche et al. (2019). Additionally, the functions include assumptions on constant technology, competitive markets and Armington assumption. The shocks introduced are changes on Chinese final demand (on aggregate level), bilateral trade tariffs between USA and China and sector specific shocks to Chinese supply and final demand. As the constructed IO-framework is demand lead model, the supply shock is introduced as exogenous disturbance that changes the output of a set sector in China that leads into a reduction of intermediate demand as a result of linkages in production networks. The demand shock are showcased with Leontief's demand-driven model and the trade cost shock is modelled as change in value-added production of set sector, similarly to Vandenbussche et al. (2019). WIOD-based model allows the convenient analysis of global and local impacts within one model as the impacts can be simulated at a level of sector of a country. However, **when introducing shocks from real-life scenarios, data alterations have to be made due to the sectoral aggregation of WIOD.**

Bröcker et al. (2010) evaluate the interregional spill overs that EU planned transport network projects have by constructing a static SCGE (spatial CGE) model able of capturing wider economic impacts. The model is fairly simple when compared to more elaborate CGE models as it covers only a household sector and a production sector with two industries, one producing tradeable (under monopolistic competition) the other local goods (perfectly competitive), due to limited availability of calibration data. In the created SCGE the changes are modelled as trade cost reductions caused by infrastructure investments as the regions (259 European and RoW) interact with costly trade (an external approach to account for passenger impacts is also created). These trade cost reductions have wide effects within the model on trade flows, production, factor prices and household welfare. The model assumes factor immobility and incorporates ideas from NEG (New Economic Geography) as the trade is modelled with Dixit-Siglitz approach but does not account for interregional income flows. The impact evaluation is done as a comparative static experiment by calibrating the initial benchmark equilibrium of 2001 based on national and regional accounts data from GTAP 6 and Eurostat and comparing that to a calibrated version of the year 2020 based on calibration of new transport cost changes with ETIS-BASE and RRG-GIS database. The comparison displays effects on physical project regions and to other regions within the model. Thus, it serves as a good base to evaluate worthwhileness of investments from a wider standpoint as it can demonstrate that a policy or an investment can be beneficial in a grand scheme of things even if it directly isn't beneficial for the investing countries by capturing the interregional spill over effects – e.g., the results of analysis can serve as an argument to gain subsidies for the project. However, the model does not capture impacts beyond monetary ones (such as noise and air pollution) which hinders its usability – especially in sustainability assessments. Therefore, extensions to the model should be made in order to make the most of it.

Nabernegg et al. (2019) analyse how different policies can induce consumption-based emission reduction in Austria and along the global value chain by using an approach combining CGE and MRIO analysis. In essence the combined model works by inducing shocks (national climate policies) that are changes in sectoral output and prices, international trade, and production-based emissions into the CGE side of the model from which these are brought to the MRIO side of the model on which the impacts – as changes in consumption-based emissions – are calculated as a comparison to the base-line scenario calculated beforehand with the MRIO. The model is based on country- and sector level data from GTAP 9 that is further aggregated into 25 sectors and four European regions, four Asian countries and seven RoW regions from which "Global SAMs" were constructed based on earlier literature to be the CGE base so that the CGE and MRIO could be calibrated to the same sectoral and regional detail. The CGE model builds on three agents (households, government and firms) and implements choices such as the Armington hypothesis to link regions with imports and exports, and the production process is represented as sectoral aggregated production with CES-function (constant elasticities of substitution). The first run MRIO is based on pre-processed economic data as well as CGE benchmark data about production-based emissions. The regional SAMs are connected with international trade data. In the analysis itself, shocks are introduced as policies to sectors that serve as "emission-hotspots", based on previous literature, expert interviews and databases as well as author assumptions. As the results display both local and international impacts that certain policies can induce at a rather disaggregated level, **the constructed model is a very strong tool for evaluating impacts and demonstrates the benefits of using connected CGE-MRIO analysis**. However, there are many limitations to the method and the model. Two major ones being the approach not being able to capture all the accumulating effects by being static and set boundaries constraining some of the effects within the model.

2.2.3 Dynamic modelling in impact studies

Mbanda & Chitiga-Mabugu (2017) analyse the effects that a large public infrastructure investment would have for South Africa (SA) and how different financing options affect the overall results with a dynamic CGE analysis. The adopted CGE model is (the publicly available) recursive dynamic CGE model PEP-1-t (meaning that each period is solved in a static equilibrium) that assumes e.g., profit maximization of firms and the imperfect substitution of different types of labour. The main changes to the standard model are namely the incorporation of spill over effects and making the unemployment within the model to reflect SA economy based on multiple previous studies on South Africa and other countries. The analysis captures both short- and long-run impacts of the planned investment as the used CGE model captures accumulation effects due to its dynamic nature and includes externalities to capture the overall spill over effects of public infrastructure investments. The main data input for the model is South Africa's social accounting matrix (SAM), other data sources and elasticities to the model originate from official governmental organizations and previous studies. In simulation of effects the world price of exports and imports is exogenous, population grows at average estimated growth rate which is an index that many other indicators are tied to, and investments are carried out in three consecutive years. The effects of different financing options are evaluated in different scenarios by adjusting the funding source for the investments (government deficit, taxation and combinations of the first two) within the model. The model is a very good tool for use in evaluation of national impacts as it presents the impacts (GDP, labour demand, CPI, output, and income) yearly and on sectoral detail. However, the model lacks global value chain involvement as it is limited to SA and therefore does not account for possible spill overs to other countries and backwards circulation of impacts.

Lecca et al. (2020) study the impacts and interregional spill overs caused by implementation of EU cohesion policy in Poland with RHOMOLO model. RHOMOLO model is a spatial dynamic CGE that is developed by the JRC (Joint Research Centre) of the European Commission. It has been used as a sole tool or in combination with other tools in different alternative versions in various EU assessments. The core structure of the model is calibrated based on 267 EU NUTS 2 regions (and RoW), where the EU regions are connected with system of MRIOTs, making RHOMOLO a suitable tool for territorial assessments of different policies and investments. The model is disaggregated into 10 sectors and within it firms are assumed to maximise profits and produce services and goods according to a certain production function, households are assumed to maximize utility and trade between sectors is costly. (Lecca et al. 2018) *A simplified (demo) version of the model is introduced in the chapter 2.3.2*. The data that the model captures originates from a MRIO table at EU 28 NUTS 2 level based on Eurostat SUTs. In the case of Poland (Lecca et al. 2020) the model is introduced with temporal shocks on public investments, production subsidies, investment subsidies (reducing risk premium), and government purchases from the market and structural shocks as reduction in transport costs, increase in TFP, and an increase in labour productivity (temporary reduction in labour market participation). By introducing the shocks to the RHOMOLO model, the impacts (with spill overs) can be examined on regional, national and EU-level over period of 50 years in terms of GDP, employment and exports among other factors. RHOMOLO is a dynamic CGE model that is able to capture impacts on a level of ample regional detail (within EU) on a somewhat aggregated level which makes it very unique and strong model within branch of CGE models. Hindrance of the model is that only limited version of the model is publicly available and even though it is possible to co-operate with European Commission (2021) to construct more elaborate simulations with the full model, use of it would be time-consuming process and need encompassing reasoning.

Montaud et al. (2020) utilize a dynamic CGE model to assess the potential impacts of different infrastructure investment plans and their financing options in Peru. They base their model on PEP-1-t much like Mbanda & Chitiga-Mabugu (2017) but further extend the model to cover infrastructure investments by linking in *“a Hicks’s neutral manner the total factor productivity of Peruvian private activities to the stocks of public infrastructure in the country”* and factors estimating the effects of exogenous variations of infrastructure on activities productivity at a disaggregated sectoral level with a primal approach, using own estimates of critical externalities parameters based on supply effects from national firm data provided by INEI. Otherwise, the model is fairly aggregated and includes one household and one government agent, eight private activities, and one nonmerchant activity and relies on standard DCGE assumptions (income side: producers maximising products, demand side: intermediate production driven by technical coefficients in production processes and Armington specification). The impacts are modelled by first defining a BAU scenario for the time period (15 years) to which the modelled impacts are reflected on after the introduction of the chosen shocks which are in this case different infrastructure plans (shocks) based on vertical gaps between infrastructure of Peru to its demand (generated by economic activity) and horizontal infrastructure gaps with Peru and comparison regions. These scenarios are defined according to growth rate of each infrastructure physical stock to be reached to fill the gap at end of the simulation period and the public spending that is required to finance the new infrastructure. This is important as the model is also used to evaluate different financing scenarios by altering the funding basis of the investments by increasing different taxes. The model is detailed and can be used to create valuable economic information on impacts of different investment plans by allowing the implementation of changes in multiple sectors within one scenario and the easy comparison of different financing options. However, main problem related to the case is the aggregated level of CGE model that precludes considering unbalanced geographical localization of assets that is very much the reality in Peru.

Sangare & Maisonnave (2018) use a DCGE model to evaluate short- and long-term impacts of a reinvestment policy in road infrastructure in Niger and its spill over effects to other sectors. The model is calibrated with 2012 SAM of Niger including ten sectors and commodities, three broad factors, four institutional accounts and one saving and investment account. The institutional account of households is further disaggregated based on survey data from INS into six types. The model utilized is PEP-1-t similar to one in Montaud et al. (2020) and the elasticises are brought from existing literature and statistics. The main specificities of the altered-model involve introduction of unemployment to the model, accounting for spill over effects of infrastructure investment on the economy’s other sectors and introduction of maintenance costs for the increase in public investment and using traditional CGE-modelling approach to model international trade. The model is capable of generating impacts after implementation of shocks (based on an investment plan called DPES in this case) that are reflected back to BAU scenario. These impacts include economic indicators such as change in GDP, overall production of different sectors, and impact on household consumption. The specific model is very good in evaluating the impacts of road infrastructure investments, though it is noted by the researchers that making extensions and alterations to the model would be beneficial upgrade in the future that would allow the evaluation of multiple types of investments such as investments in sanitation, a matter very important in developing countries such as Niger.

Collste et al. (2017) use a dynamic systems model to evaluate potential impacts that a large PV investment to Tanzania would have on progress towards three SDGs locally. The applied model developed by Millennium institute is the iSDG model that is based on Treshold 21, a dynamic scenario tool used in numerous development projects around the world over the years (Collste et al., 2017) and the model most suited for analysing wide-range sustainability impacts according to Allen et al. (2016) who evaluated 80 different modelling tools for the matter. iSDGs purpose is in evaluating impacts related to UNs sustainable development goals on a sub-national, regional and national level and it considers a vast number of indicators, causalities and feedback loops based on extensive amount of literature. However, it is recommended to use expert interviews and data sources (both quantitative and qualitative) case by case, if possible, when building explicit models and scenarios as it yields better results, although mainly IEA and World Bank data was used in case of Tanzania. The iSDG model consists of three top-sectors under each of which are 10 sectors and in combination over 1 000 stock variables. The variables for development planning are modelled as endogenous including population, aggregate production, the demand and supply of energy and their determinants whereas the allocation of public resources between distinct governmental subsectors is usually modelled as exogenous. By calibrating the model with existing (or determined) relationships and data, the model can be eventually run to yield results based on causal relationships. These causal pathways and chains generate positive or negative outcomes depending on various interactions between factors and are portrayed by statements such as *“learning conditions are improved by access to information communication technologies. Access to electricity in rural areas may also increase the areas’ attractiveness for good quality teachers”*. As different causal pathways are connected to each other to form loops, accumulating impacts are captured to represent the real-world impacts. The model is able to present the defined results on a desired timespan – in case of Tanzania, impacts on 3 SDGs in 15 years – based on the different investment scenarios in quantitative terms. The iSDG model is a good tool in capturing wide range of sustainability impacts on a national level as it joins both quantitative and qualitative data more than the "regular impact assessment models" such as stock CGEs. By doing so, the distinct model and scenario building requires vast amount of laborious information gathering, decreasing its attractiveness for small project use. Another drawback of the model is the lack of international connection points in the model, thus it might not be applicable for use in more open economies.

2.2.4 Synthesis of statistical modelling studies

Examination of different models demonstrates that small changes such as implementing population growth or financing options into the scenario (Mbanda & Chitiga-Mabugu, 2017; Montaud et al., 2020) has a clear effect on final simulation results. Similarly the databases used, assumptions made and geographical limitations impact the results, but help decisionmakers by providing information that is relevant for the decision at-hand (Bröcker et al., 2010; Chen et al., 2016). However, in these cases it is important to account for inducing and multiplicative impacts even though they might not clearly compartmentalize in the modelling outcomes as downstream impacts effect upstream ones and vice versa.

The literature review demonstrated that modelling approaches should be considered case-by-case but at the same time it displayed that some approaches are more suitable for certain types of analyses than others. Dynamic CGE models are very good in capturing the long-term accumulating effects at a bound location where the model can be shaped to imitate the real-economy with varying indicators and economic functions (Mbanda & Chitiga-Mabugu, 2017; Montaud et al., 2020; Sangare & Maisonnave 2018). By using a base-model such as the PEP-model Sanagare & Maisonnave (2018) were able to tailor the model to represent the Niger economy with implementation of official statistics and location-bound parameters such as the unemployment rates that differ from unemployment rates introduced by Mbanda & Chitiga-Mabugu (2017). By introducing similar small alterations a stock-model can become a quick tool to analyse wider-economic impacts of new policies in specific locations. By using a set standard model with only altering indicators and SAMs one could even evaluate impacts that a specific investment would have around world if the only purpose were to provide aid or enhance overall global sustainability. However, more often than not the cases are tailored to specific individual national needs that benefit from more elaborate model of that economy as in Montaud et al. (2020). At this time, trade-off is made in CGE modelling when more restricted models are created as they rarely account for the world-economy in detail as usually within the models global trade is expected to continue in similar or pre-determined manner and the actual nations are seen to not have impacts on world-prices (Sangare & Maisonnave, 2018). Obviously, exceptions in the scope exists like in Lecca et al. (2020), but then some local-level detail is usually lost, which can be the case for static CGE models (Bröcker et al., 2010) in addition to dynamic ones.

Multiregional input-output models do not simulate the “real-world” impacts as well as CGE models even though they are often based on more or less the same core statistics that are used to build the ones for CGE models. The lack of economic theorems does limit the usability of the models when certain shocks are considered but at the same time they serve as more detailed tools for capturing wide-spread impacts as they tend to be more disaggregated than CGE-models. Another major benefit is the global connections that can be made with direct use of GMRIO models (Rodríguez-Serrano et al., 2017; Simola, 2019) or by nesting distant regional IO-tables together (Chen et al., 2016). However, in these cases the sectoral aggregation is not as detailed as in local level effectiveness evaluations (Faturaya et al., 2020; Malik et al., 2014; 2016), but still considerably larger than that in typical CGE-assessments. It has been also demonstrated that different databases and approaches can be combined, though assumptions and limitations have to be made to make the connection process plausible (Rodríguez-Serrano et al., 2017; Nabernegg et al., 2019), implicating that connecting existing MRIOs to one and other is another option for local-to-global analyses.

Connecting CGE and MRIO approaches is unusual but not unheard off as Nabernegg et al. (2019) were successfully able to create a CGE-MRIO model to evaluate wide-spread emission impacts of five potential Austrian policies. Even so, it is very diligent task requiring assumptions, connections and aggregation. However, in future reminiscent models can become more mainstream if different database and model providers such as GTAP start consistently making globally connectable SAMs as this would ease the workload considerably. Other interesting opportunities used in literature include the FISA framework (Rodríguez-Serrano et al., 2017) that captures multiple sustainability impacts within one simple framework. Regardless, different sustainability frameworks have been already created, so FISA or similar framework would require acceptance from policymakers on occasion or a supranational organization to make their official recommendation backed by scholars to become conventionally viable. Same mentality applies on additional statistics used in literature as more official databases like UN materials database can be considered reliable on spot whereas survey data (Montaud et al., 2020), benchmark-scenarios (Malik et al., 2014) and external-impact data (Futuraya et al., 2020) require check-ups from the adapters of the data and results created.

Dynamic systems models (Collste et al., 2017) can be seen as their own entity though they might provide the best representation of the real-world by combining expert opinions, official statistics and analytically drawn causal linkages. Concurrently, the vast amount of work put in creation of simulations in individual cases is the approaches hindrance as resources put into effectiveness evaluations tend to be limited. Regardless, DSMs are very viable option for analysis of developing economies (such as those of Africa) where the developmental differences are drastic, and causalities between different SDG can be drawn relatively straightforward compared to same procedure in well-interconnected developing countries.

Ultimately, the world is more dynamic and reactive than any CGE, MRIO or DSM model can ever account for. Hence the idea behind any effectiveness evaluation is *a rough estimate to a relevant question is better than a perfect answer to something unnecessary*. With this sentiment, applicability of different modelling approaches for the purposes of international effectiveness evaluation in context of Finland is carried in chapter 2.4 after existing models and databases are presented in the following chapter.

2.3 Existing statistical tools and databases of interregional impact assessments

2.3.1 Transnational input-output databases

A plentiful of models and databases for impact and global value chain analysis exists for the use of researchers, policy makers and companies alike. Some of these are publicly available, some require paid licensing and access to some are completely restricted for the general public. The applied models introduced in chapter 2.2. present only a glimpse of available applications that different institutions, organizations and governments have created to evaluate impacts. The European Commission alone has tens if not hundreds of models for use in effectiveness evaluations of different purposes and Allen et al. (2016) were able to identify 80 distinct scenario models for sustainability assessments in just 40 or so academic journal articles.

In this chapter an overlook on some of the existing models and databases that can be utilized in modelling of shocks and tracing of impacts across borders is presented. First, a table of available inter-country input-output databases is presented with description of the distinct features and issues related to them. Second, a table on supporting databases that can be utilized in support of impact assessments universally is introduced. Finally, a table on prominent platforms and base models for impact assessments is provided with a closer look on two tested models.

Table 4. *Available input-output databases with international coverage (based on Johnson, 2018; Remond-Tiedrez & Rueda-Cantuche, 2019; Tukker et al., 2018 and market research)*

Name	Coverage	Years	Countries	Sectors	Updates	Availability
WIOD (2016 release)	Global	2000–2014	43 countries, RoW region	56 industries	Infrequent	Public
EORA	Global	1990-2015	190 countries	26 industries uniform, more by country	Yes	Academic use, paid licensing
EXIOBASE v. 3	Global	1995-2011	44 countries, 5 RoW regions	163 industries, 200 products	No	Public
GTAP 10	Global	2004; 2007; 2011; 2014	121 countries, 20 aggregate regions	65 sectors	Infrequent	Paid licensing
GTAP 7	Global	2004	113 regions	57 GTAP commodities	Infrequent	Paid licensing (unless special permission)
OECD-WTO TIVA	Global	1995-2015	62 countries & RoW	36 sectors	Yes	Public
OECD ICIO	Global	1995-2011; 1995-2013	64 countries, RoW, split tables MEX & CN	36 industries	No	Public
IDE-JETRO	Asia, US, BRICS	1985; 1990; 1995; 200; 2005	10 countries	76 sectors	No	Public
ADB-MRIO	International	2000; 2005-2008; 2011	45 economies	35 industries	Yes	Public
YNU-GIO	International	1997-2012	29 countries & 5 world regions	35 sectors	No	Public

Table 4 presents the IO-databases with wide international coverage, connecting cross-industry and inter-country input-output linkages. For the most part these tables are created from national input-output or supply-use tables that are connected to one and other with bilateral trade data but differ from methodological choices taken in harmonization of data (Johnson, 2018). More detailed descriptions of the linking process of individual GMRIOs can be found in Tukker et al. (2018) for the majority of the distinct GMRIOs. Despite the databases being representations of the global economy, certain awareness has to be taken when applying the models to real-world situations. The data used to build the databases and the models following is imperfect as technical features (such as classifications) of national IO-tables vary by country, the year-by-year data does not always match, and some data is always missing (Johnson, 2018), and lacks timeliness for the most part (Tukker et al., 2018). Another major concern is the aggregation of data as different choices in clustering of industries easily results in notable distortions. This is especially relevant when considering the use of different GMRIOs as usually the national tables that the global tables are constructed from are in more disaggregated level (Johnson, 2018) than the global tables to be constructed, and virtually all GMRIOTs have adjusted these in order to make the final tables balanced (Tukker et al., 2018).

The final MRIOTs differ from each other on multiple accounts (sectoral aggregation, level of global coverage and reference years) as displayed by the table 4. However, the table does not capture many of the differences and strengths that the databases have compared to each other. For instance, Exiobase is very suited for environmental analyses (Tukker et al., 2018) as it covers multiple accounts of raw materials, water uses and land types, Eora holds variety of environmental satellite accounts for profound environmental analyses such as biodiversity accounts (Rodríguez-Serrano et al., 2017), and GTAP itself has variety of existing frameworks and CGE models created on it for use in impact analyses (Johnson, 2018). Therefore, a special consideration should be taken when choosing the databases to be used for a specific type of impact assessment. Pieces of different databases can be utilized in combination if the main database used to build a model lacks needed parts as did in Rodríguez-Serrano et al. (2017), though one should be aware that data from different GMRIOs does not yield the same results even if aggregated to same sectoral level. Same applies when individual GMRIOs are aggregated based on different classifications and compared to one and other. (de Koning et al., 2015; Piñero et al., 2015; Steen Olsen et al., 2014). Moreover, problems occur when connecting specific superior national SUT/IO-data into GMRIO if not done right (Tukker et al., 2018).

Multiple other MRIO tables for more restricted areas have been built in many studies and by organizations and countries alike, that did not meet the criteria of table 4 such as single national input-output tables and modified tables serving a single case. Some promising intercountry IO-tools are being developed, such as the FIGARO tables EU-IC-SUIOTs (Johnson, 2018), that were released in 2021 are used to analyse the environmental and socio-economic effects of globalization in EU (Remond-Tiedrez & Rueda-Cantuche, 2019). However, the tables are still considered experimental until the methods have been agreed among EU countries, more official data has been introduced to the tables and when the tables are created more regularly (Eurostat, 2020).

Table 5. *Supporting international statistical databases for impact evaluation*

Name	Coverage	Data description
SHDB	Global	Social risk
NREL	US & International	Energy and energy efficiency
Global Material Flows Database (UN)	Global	Material use
UN Comtrade	Global	International trade
ITC Trademap	Global	International trade
IMF IFS	Global	Financial data
RRG-GIS	Europe	Transport networks
Ecoinvent	Global	Life cycle inventory
STAN (OECD)	Global	Industrial Statistics

Table 5 presents some of the more specific relevant individual databases identified during research process that can be used in designated impact assessments. Naturally, te table is not all-encompassing as several statistic agencies and supranational organizations such as Eurostat, FAO and the United Nations have created multitude of databases for different purposes. Use these and other different "external" databases should be considered on case-by-case basis as some of them are applicable for use of analyses as such, some of them are easily adaptable to be used in conjunction with other databases e.g., SHDB with WIOD, Eora (Rodríguez-Serrano et al., 2017) or IO-tables serving a single purpose (Mattila et al., 2018) and some require magnitude of alterations to be compatible with the reference databases.

2.3.2 Statistical tools and models

Table 6 presents modelling tools studied during the research process used in impact evaluations. These models can be either used to model shocks to an economy or to trace connections within global value chains. The models are a result of expert work and are based on official statistics, established economic theory and novel techniques. Basis of operationality in models differ, but more elaborate models are usually based either on GEMPACK or GAMS modelling software and language (e.g., PEP-1-t and Trade-Scan). MATLAB and Excel are also tools that are very much employed in IO modelling as for instance Envimat is based on Excel and R, and many of the models have Excel tables as inputs and outputs (e.g., RHOMOLO, Trade-Scan). Similarly to databases, different models are more suitable for certain purposes than others. Therefore, knowing the issue at hand and the desired outputs of the project beforehand is important in order to choose the best option early in the evaluation process as internalising the principles let alone the operationality of a single model is a time-consuming task.

Table 6. *Statistical tools for impact evaluation*

Name	Coverage	Description	Availability	Used in
RHOMOLO	EU regions	Spatial computable general equilibrium	Demo version upon request, full restricted	Lecca et al. (2018)
FIDELIO	Global (WIOD base)	Dynamic econometric IO model	Restricted, publicly available application 2022	
TRADE-SCAN v.2	Global (WIOD, Exiobase or OECD-ICIO base)	Global value chain analysis	Upon request	
ENVIMAT	Finland	EEIO long-term simulation model	Upon request	Piñero et al. (2018)
IELab	Individual countries, global version	Virtual laboratory for creating MRIOTs	Paid licensing	Malik et al. (2014; 2016); Chen et al. (2016); Faturaya et al. (2020)
I-JEDI	Global (individual countries)	Evaluation of renewable energy projects gross economic impacts	Public	Faturaya et al. (2020)

PEP-1-T	Nation specific	Recursive dynamic model (CGE)	Public (GAMS code & user guide)	Mbanda & Chitiga-Mabugu (2017); Sangare & Maisonnave (2018); Montaud et al. (2020)
iSDG	Nation specific	Dynamic systems model	Demo version upon request	Collste et al. (2017)

FIDELIO is a multisector model developed by JRC for the purpose of sustainable production and consumption policy analyses. It includes 28 European and 7 other major countries disaggregated into 56 sectors and products for the analyses, and is based on economic theory, integrating both neoclassical and New-Keynesian features within the model structure. (Rocchi et al., 2019) Unfortunately, the use of tool is restricted for the purposes of European Commission for now. **Envimat** is a very detailed EEIO model representing the Finnish economy. The core of the model is based on Keynesian framework and it can be used to model the environmental effects of production. (Mäenpää et al., 2017) **PEP-1-t** is a recursive dynamic model based on GAMS code and established economic theory that can be used to evaluate economic and socio-economic impacts of different investments and policies as described in Sangare & Maisonnave (2018) and Montaud et al. (2020). Besides the standard PEP-models that can be applied in different country-settings, other PEP-models exist that can be used for multiregional analysis based on GTAP 8 data.

The **iSDG** model is a policy simulation tool (dynamic systems model) for the purpose of analysing regional impacts and development towards United Nations sustainable development goals. The basic features of the model are described in chapter 2.2.2. The **I-JEDI** model is publicly available economic model created by NREL that can be used to estimate the gross economic impacts of biopower, geothermal, solar PV or wind technology projects within a specific geographical domain (a set of globally disperse individual countries is available within the model). The model provides estimates on direct, indirect and induced jobs, earnings, output and the GDP created by the project on aggregated level of ten sectors applying IO-methodology. As the models inputs (project specific requirements) are limited and either defaults (derived from interviews with industry experts and project developers as well as expert sources) based on the size and the location of the project or entered by user, detailed data about the project is needed for accurate simulation results. (Keyser et al., 2016) **IElab** is a virtual laboratory platform for the creation, compilation and updating of MRIO tables. It was first developed to be the most detailed subnational IOT of Australia (Malik et al., 2019), but since that it has been used to create IO-tables for other regions as well; US (Faturaya et al., 2020), Indonesia and Sweden for example. Even though the access to some of created tables might be restricted, the main benefit of the tool is in its ability to automate and streamline the process of creating customized IO-tables. It can also be used for footprinting, quantifying uncertainty in data and triple bottom line analyses. (Malik et al., 2019)

RHOMOLO is European Union's spatial dynamic computable general equilibrium model that can be applied for use in variety of policy analyses (Lecca et al., 2019; 2020). The full-fledged model is able to introduce variety of shocks into a system and produce long-term results on multiple accounts and high regional level, making it effective tool for official use. Access to the demo version of RHOMOLO was granted for the purposes of the study and model tested. The demo model can be implemented with three types of shocks (up to 5% increase or decrease in total factor productivity, labour productivity and reduction in transport costs) by region based on regional classifications (Thissen et al., 2019). Simulating the selected changes runs the model in EU Commission servers resulting in the heat map displayed in figure 6 and downloadable excel file on the changes on set indicators (e.g., GDP, exports, investments and employment) by region. Unfortunately, there is no sectoral disaggregation of the results and only very limited number of types of shocks that can be modelled exist for the restricted version. Hence, it is not applicable for proper impact scenario analysis unlike the real model.

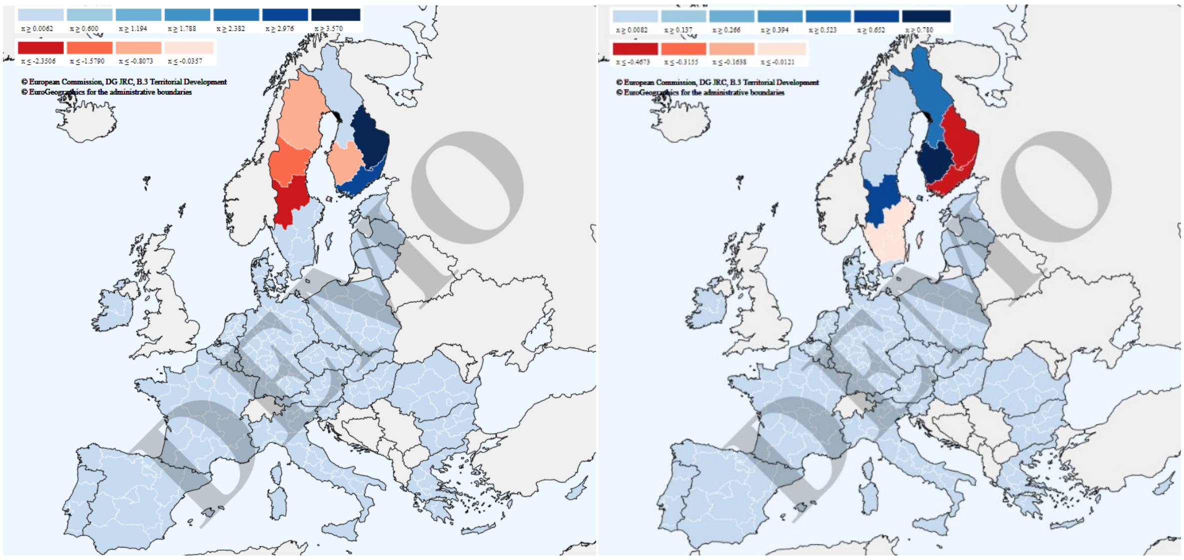

Figure 6. *RHOMOLO modelled Impacts of factor productivity rising in SE Finland and decreasing northern Sweden on GDP (left) and imports (right)*

Trade-Scan is a tool for global value chain analysis that enables less-experienced users in the field of economic analysis to perform decomposition of factors embodied in exports and in final demand with a simple graphical interface. Hence, users can use it on customized global value chain analysis and e.g., evaluate the overall impact of certain country's telecommunications sector on other countries financial services sector. The possible combinations are numerous, and the selected output variables in queries can include total primary inputs, value added, employment effects, CO_2 impacts and some variants. An example of individual scenario building is displayed in figure 7 below.

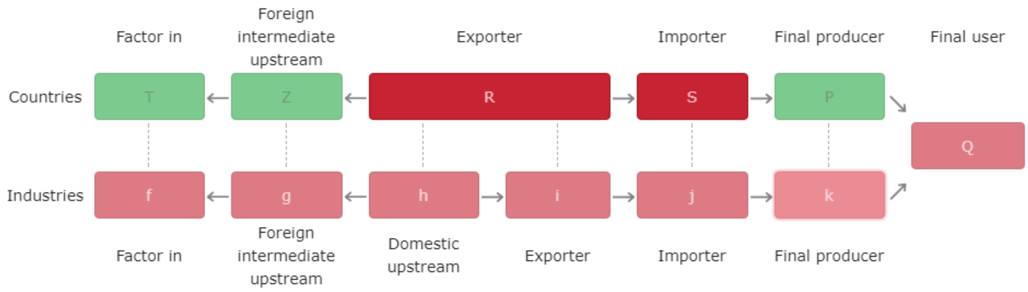

Figure 7. *Global value chain analysis in Trade-scan ad-hoc module*

The underlying methodology behind the model is in input-output basics and a novel mathematical framework by Arto et al. (2020) based on matrix algebra and input-output economics that allows for a full decomposition of bilateral gross trade from country perspective (Román et al., 2020). The model can be fed with data from either WIOD, Exiobase or OECD-ICIO tables (and soon FIGARO). Therefore, it is limited by the chosen database on selectable options such as the reference years. Simulations based on the chosen criteria are run within the software using GAMS by external users (or on EU servers by only Commission members for now) resulting in Excel worksheet with indicators. Specific calculations with the model can be further created by contrasting multiple scenarios with small alterations to each other or just as is for a set scenario. Despite being a simple tool by usability it does require a basic understanding of underlying logics on international trade, global value chains and input-output economics as well as rigorous following of instructions for a worthwhile use.

2.4 Synthesis and contextual analysis of modelling methods

2.4.1 Applicability to Finnish value chain and sustainability analysis

The field of effectiveness evaluation is growing around the globe with research being made at an accelerate pace. Despite the geographical dispersion, the methodologies, databases and frameworks used in the field are similar at their core. The changes happen mostly on the assumptions when the analysis is applied in more specific domain and the data is harmonized. There are simple existing models that allow non-experts of the field to conduct analyses on surface level to get the gist of the effects. However, creation of more advanced specific case-bound models enables the in-depth analysis of the desired impacts on detailed level, though it requires vast amount of both time and expertise.

The literature review was set to find out methods that can be universally applied even if they are bound to a specific location. This applicability is now appraised in the context of Finland, a country that is positioned downstream in overall context of global value chains. Effectiveness evaluation is not a new phenomenon in Finland as both public and private organizations use it often as a basis for project and investment evaluations, multiple databases and frameworks have been created to diversly support these analyses, and many studies have been conducted. More recently in Finland IO-based impact assessment has been applied in analysing social effects of bioeconomy value chains on a local level (Mattila et al., 2018), socio-economic effects of bioenergy-based investment strategy (Lehtonen & Okkonen, 2016) and new bio-oil production (Okkonen & Lehtonen 2017) on a regional level, the sector arrogation bias of EEIO models (Piñero et al. 2015) on a national level, and the raw materials embodied in imports on an international scope (Piñero et al. 2018). Utilizing global data and classifications is implemented in multiple studies by scholars, but only Piñero et al. (2018) truly takes advantage of a global MRIO by utilizing Exiobase as the key model to capture international connections. A clear shortage in studies modelling the impacts of internationally originating shocks on the Finnish economy is observed. Hence, the rest of the chapter focusses on evaluating the applicability of methodologies and models used globally in impact assessments to the context of Finland based on the literature review.

Ultimately, dynamic computable general equilibrium models are the top approaches to model long-term impacts of policies and investments on a national level. Extending the approach to global level does however have its limitations as introducing magnitude of countries and their unique values on variables makes the model very complex and computationally heavy. Consequently, there are not many available models for this purpose and more elaborate ones such as RHOMOLO are not available for public use. Same restrictions apply on most of the static CGEs as well, though it is possible to combine the static approach with MRIO model to cover international connections (Nabernegg et. al., 2019). Therefore, one possibility with CGEs is to model shocks locally within a CGE model and bring the effects into a GMRIO on which the wider economic effects can be assessed in multiple accounts. Instinctively, the approach can be extended to further connect the effects to more detailed national accounts. This in turn requires more connections, assumptions and harmonization to be made in order to match the sectoral aggregation among other things, thus increasing the margin of error considerably.

Similar connection approach can be used when utilizing MRIO modelling by itself. Although, three more straightforward approaches can be used. First, creating nested input-output tables of specific regions, nations or areas together somewhat like Chen et al. (2016) to which shocks can be introduced. However, this approach has limited ability to examine the global value chain and account for the induced global effects. Second, the shocks can be implemented to existing inter-country IOTs and further expanded to national tables. Third, the shocks can be modelled with existing GMRIOs such as WIOD or Eora as Finland already exists in the databases. The benefit of this approach is in its sectoral detail, existing connections in the models based on bilateral trade, simplicity and the ability to be readily connectable to several sets of satellite accounts to capture wide range of sustainability impacts. Finally, considering the use of base tools such as Trade-Scan (if available), IElab and PEP-models is worthwhile if the scope of the evaluation falls under the extent of the tools as this can save both time and money. Based on the literature review following methodologies are potentially applicable to assess how the benefits of financing foreign ventures circulate back to Finland:

- Modelling local impacts with CGEs or distinct macroeconomic functions and connecting impacts back home with inter-country MRIOs
- Connecting distinct MRIOs together with either imports, exports or bilateral trade and modelling impacts within that system
- Using existing GMRIO models that already capture the interconnectivity of global value chains
- Utilizing existing tools for the purposes of the analysis such as RHOMOLO and Trade-scan if applicable and available for use
- Considering other approaches that did not fall under scope of the literature review such as stock-flow consistent models and world trade models

The suitability of these approaches was reflected on Finland but they are universally applicable for the most part. However, some countries might lack the data required for the easy use of the approaches, like utilizing only GMRIOs as for example WIOD covers only 43 individual countries. In these cases, another approach is most likely more suitable, even if the data could be brought and adapted to the system from other sources as it would require changes to the RoW category in the data table and would not have the existing trade connections to account correctly for intermediate production. Hence, choosing the approach should be done on case-by-case basis. Next a final analysis based on the predetermined needs of the study and the literature review is conducted in retrospect of the introduced possibilities for the case at hand.

2.4.2 Applicability to meet predefined grounds and objectives

Research questions determine that suitable model for the use in this thesis should be able to capture the downstream effectiveness of foreign investments, the sustainability impacts of set investments and indicate how global value chains affect the results. Hence a preliminary research was set out to find the optimal methods of analysing wider-economic impacts utilized throughout the world. Literature review clearly demonstrated that input-output and computable general equilibrium analyses are the most utilized tools for the purpose. However, the models have distinct features, and the scope of the study is limited to finding and utilizing only the most suitable approach, a decision about further scrutinization of the method has to be made before continuing further exploration of the method (chapter 3). For these purposes, an additional analysis of the literature introduced earlier in table 3 (appendix A) was done based on predetermined criteria.

Table 7. *Analysis of modelling methods capabilities thorough research questions*

Model type	Impact methodology	Main sustainability indicators	Local impacts	Sustainability	Global impacts	Manageable workload	Authors
MRIO	Change in demand	Economic, environment	X	X	0	0	Faturay et al., 2020
MRIO	Change in demand	Socioeconomic, environmental, social	X	X	X	X	Rodríguez-Serrano et al., 2017
CGE	Change in supply (and demand)	Economic	X	0	0	X	Mbanda & Chitiga-Magubu, 2017
IO	Change in technology	Economic, socioeconomic	X	X	0	X	Malik et al., 2014
CGE	Change in supply (and demand)	Economic	X	0	X	0	Lecca et al., 2020
DMS	Change in technology	Socioeconomic	X	X	0	0	Collste et al., 2017

CGE	Change in supply (and demand)	Economic, socioeconomic	X	X	0	0	Montaud et al., 2020
CGE	Change in technology	Economic	X	0	X	0	Bröcker et al., 2010
MRIO	Change in technology	Environmental	X	X	X	0	Chen et al., 2016
IO	Change in demand	Economic, environmental, social	X	X	0	0	Malik et al., 2016
IO	Change in demand (and supply)	Economic	0	0	X	X	Simola, 2019
CGE	Change in demand (and supply)	Economic	X	0	0	X	Sangare & Maissonave 2018
CGE-MRIO	Change in demand (and supply)	Environmental	X	X	X	0	Nabernegg et al., 2019

The compressed analysis is visible in table 7 which displays if the studies capture set parameters to sufficient extent and if the methods are applicable to other **similar** scenarios without too much **workload**. **Global impacts** refers to capturing the international effects of investments, concurrently **local impacts** refers to capturing the local impacts in detail, and **sustainability** refers to capturing the economic, environmental, and social impacts related to the cases to adequate standard. To be noted; in the case of sustainability, in some of the studies the sustainability results were only displayed with certain indicators but were or could be extended to cover more grounds.

The analysis clearly displays that IO-based models are better in capturing the global impacts within the domain of analysed cases which is not unexpected as the strength of CGE models lies in their ability to capture the real-world imitating impacts on spatially restricted areas in good detail, drawback of which is that complexity of the models increases toweringly when different economies are covered within a single model. MRIO models clearly shine in their ability to capture sustainability impacts which is due to their ability to capture them with simple extensions to the economic base models. The standout of the analysis is the case of Rodríguez-Serrano et al. (2017) who cover multiple sustainability indicators with one model, and though the modelled case required rather large workload in terms of gathering data, the actual method of connecting sustainability impacts is not as laborious. What is special about this case as well as the case of Chen et al. (2016) and Nabernegg et al. (2019) is the utilization of global MRIOs to capture local effects either directly or as a part of scaled model. This allows both the capturing of the international impacts and analysing of the global value chains that are crucial aspects in terms of answering the research questions of the thesis.

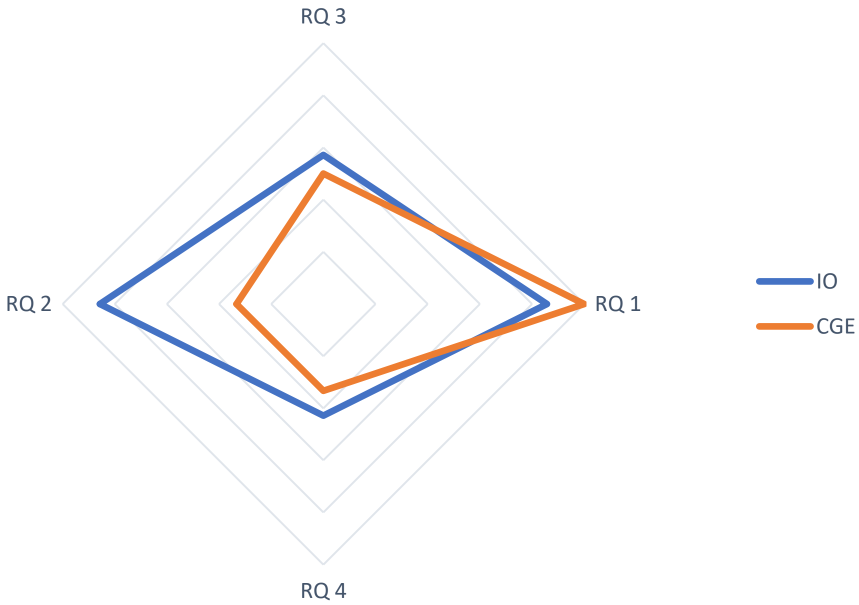

Figure 8. *Methods of CGE and MRIO modelling reflected on the research questions*

Figure 8 displays how the different models in table 7, grouped further into IO and CGE-modelling, are able to answer the research questions to sufficient extent. Based on the table 7, RQ 1 artificially refers to local impacts, RQ 2 to sustainability impact, RQ 3 to global impacts and RQ 4 to manageable workload in the figure above. Reflecting the findings of the analysis on the earlier introduced possibilities to assess foreign investments in the context of Finland, **it was proposed that GMRIO databases was to be used either as is or connected to a sub-national MRIO table as a base model for the purposes of the effectiveness evaluation in this thesis and similar projects**.

3. MULTIREGIONAL INPUT-OUTPUT ANALYSIS

Based on the literature review multiregional input-output analysis was recognized as the most applicable solution for further analysis. Developed in 1930's by Wassily Leontief, IO analysis is an analytical framework that is applied extensively in todays impact analyses addressing countless topics such as economy, environment, energy, trade, ecology and labour due to its nature to capture interconnections between sectors, regions and even nations (Wiedemann, 2009). The core of the analysis is that different sectors within the economy need each other's inputs to produce goods, making the sectors interconnected (Raa, 2006 p. 14). Multiregional input-output analysis further captures these connections by linking different regions (and their industries or commodities) together, enabling detailed analysis on wide geographical scope (Wiebe et al., 2018). The following chapters present a brief description on theory behind multiregional input-output modelling, the approaches taken in literature to connect existing sub-national IO-tables to global ones, and the extensions and restrictions of MRIO analysis.

3.1 Input-output modelling

3.1.1 Single region input-output model

Input-output models (also known as interindustry analysis) are used to analyse the interdependencies of industries in an economy. They are made up of systems of linear equations that describe the distribution of industries products thorough the economy at their most basic form – there are as many linear equations as there are variables in a single model. However, models can be extended to include additional detail, elements and limitations. Input-output modelling has seen considerable rise in use as computational capacity has improved and is now widely adopted analysis tool of many of governmental and supranational organizations. (Miller & Blair, 2009 p. 1-3)

An overview of simple input-output framework can be seen in figure 9. It displays the position of different industries in the economy, the value-added and captures the multiplicative effect of producing goods. In theory, it can consist of as many sectors as there are sectors in the economy, but due to data constraints the sectors are often aggregated to level of industries e.g., all activities directly related to restaurants, food delivery and hotel business are allocated under industry "accommodation and food services". Ideally input-output tables are based on surveyed data (inputs, outputs, transactions etc.) from all actors in the economy but in reality, this is not possible due to sheer amount of work it takes and the unwillingness of companies to share their detailed data which is why aggregation and estimation is necessary step in every case. The missing data can be estimated with targeted surveys to individual companies, publicly available data and mathematical approximations. (Miller & Blair, 2009)

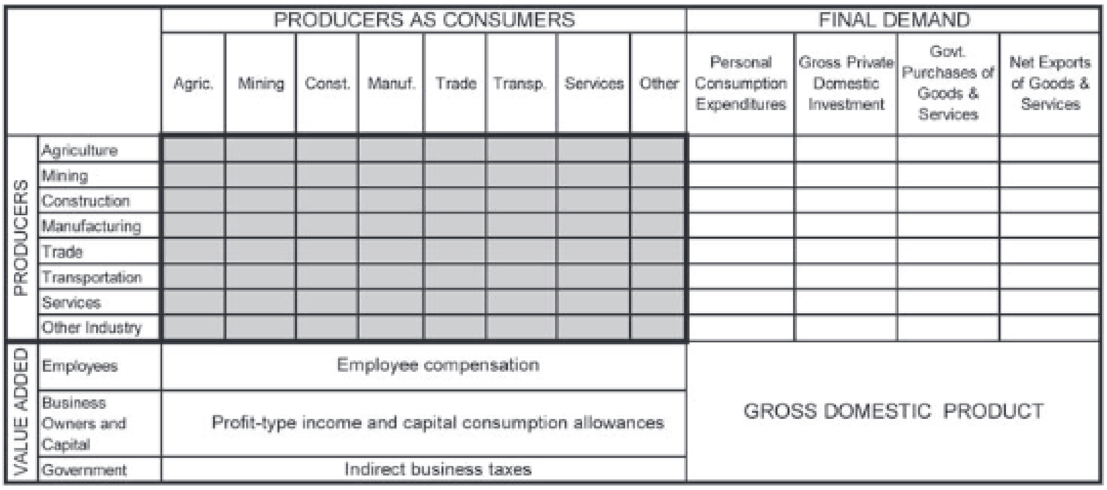

Figure 9. *Basic input-output framework (Miller & Blair, 2009 p. 3)*

The core of the table consists of different industries, value-added activities and final demand. The columns in the table describe the formation of inputs required to produce each industries output whereas the rows describe the distribution of set industry's output throughout the economy. (Miller & Blair, 2009 p. 3) Ultimately the production of a sector is driven by final demand but majority of total inputs consists of intermediates from other sectors that the input-output framework is able to capture (figure 9). An additional key takeaway is that the total output of a set industry is equal to its total input and that the industry can serve as an intermediate supplier to itself. The units of measure in input-output tables are usually captured in monetary terms as it is a uniform unit that can serve all the sectors, even though the flow of goods can also be captured in physical terms (Miller & Blair, 2009 p. 10-11). The mathematical description on foundations of input-output tables and economics is well captured in previous literature and therefore limited to level of MRIO modelling in this thesis, for more detailed description of single- and different approaches to multi-country input-output modelling readers should consult Andrew et al. (2009), Miller & Blair (2009) and Raa (2006).

3.1.2 Many-region input-output model

As input-output table captures the interconnectivities between sectors it is a suitable tool for analysis on multiple levels of economy – it can cover a single city, region, nation, area of world or the entire global economy. Multiregional input-output tables (MRIOT) are connected systems of input-output tables that capture the interregional effects of producing goods and services. The connection of regions in MRIO models is typically done with trade flows. By splitting up bilateral trade data into intermediate and final use, traded commodities are separately accounted in the intermediate and final consumption. (Andrew et al., 2009) This is a necessary step to avoid double counting of exports and imports. In essence MRIO framework operates similarly to a regular input-output one, just on a wider scope. Besides having the regular input-output tables (sub-tables) in the MRIOT diagonally, it implements tables representing the trade between regions as demonstrated by the figure 10 below.

		Region A		Region B	
		Industry 1	Industry 2	Industry 1	Industry 2
Region A	Industry 1				
	Industry 2				
Region B	Industry 1				
	Industry 2				

Figure 10. *MRIOT intermediate matrix with two regions and industries*

In the MRIOT regions *A* and *B* can represent different countries or different-scale regions (e.g., Pirkanmaa, Norway or Western-Europe) and the industries can be any groupings of sectors as long as it is same for different regions (ideally). The intermediates matrix of the presented MRIOT can be expressed in mathematical terms

$$Z = \begin{bmatrix} Z^{rr} & Z^{rs} \\ Z^{sr} & Z^{ss} \end{bmatrix},$$

where *Z* represents the total intermediate matrices, *r* the region *A* and *s* the region *B*. At this point interregional industry linkages can be considered by separate matrices as then any number of industries can exist for regions and some intermediate matrices can even be un-squares (e.g., 2 x 3). For clarity, the following demonstration is done for the case presented in figure 10 with square intermediate matrices. The output of region *A*'s industry 1 can be expressed

$$x_1^r = z_{11}^{rr} + z_{12}^{rr} + z_{11}^{rs} + z_{12}^{rs} + f_1^r, \quad (1)$$

where *f* represents the intraregional sales to final demand, other first two terms the intraregional interindustry sales and latter two the interregional interindustry sales. Similar equations exist for the other three output variables in the two-region model. Regional input coefficients and interregional trade coefficients can be further expressed as

$$a_{ij}^{rr} = \frac{z_{ij}^{rr}}{x_j^r},\ a_{ij}^{ss} = \frac{z_{ij}^{ss}}{x_j^s},\ a_{ij}^{rs} = \frac{z_{ij}^{rs}}{x_j^s},\ a_{ij}^{sr} = \frac{z_{ij}^{sr}}{x_j^r}\ , \quad (2)$$

that describe the intermediates needed from other regions and industries to produce unit of output. Here the denominators are gross outputs of the sectors in receiving region for interregional trade coefficients. With this analogy the equation (1) presented for output of industry region *A*'s industry 1 earlier can be re-expressed

$$x_1^r = a_{11}^{rr}x_1^r + a_{12}^{rr}x_2^r + a_{11}^{rs}x_1^s + a_{12}^{rs}x_2^s + f_1^r. \quad (3)$$

Similar expressions exist yet again for the other three output variables in the two-region model. This is reminiscent of its single-region variant *x* = *Ax* + *y*. To construct a complete coefficient matrix all output terms have to be moved to the left leading into

$$(1 - a_{11}^{rr})x_1^r - a_{12}^{rr}x_2^r - a_{11}^{rs}x_1^s - a_{12}^{rs}x_2^s = f_1^r, \quad (4)$$

which can be shaped into coefficient matrix

$$A^{rr} = \begin{bmatrix} a_{11}^{rr} & a_{12}^{rr} \\ a_{21}^{rr} & a_{21}^{rr} \end{bmatrix}.$$

By doing the same procedure for rest of the output terms similar matrices can be formed. These can also be displayed in the form

$$A^{ss} = Z^{ss}(\hat{x}^s)^{-1},\ A^{rs} = Z^{rs}(\hat{x}^s)^{-1},\ A^{sr} = Z^{sr}(\hat{x}^r)^{-1}. \quad (5)$$

From these four matrices and separate equations for different final demands based on equation (5) can be comprised to

$$(I - A^{rr})x^r - A^{rs}x^s = f^r, \quad (6)$$

$$-A^{sr}x^r + (I - A^{ss})x^s = f^s,$$

where f^r is the final demand vector for region *r* goods and f^s is the final demand vector for region *s* goods. Therefore, the complete coefficient matrix for a two-region model consists of four sub-matrices and is expressed

$$A = \begin{bmatrix} A^{rr} & A^{rs} \\ A^{sr} & A^{ss} \end{bmatrix}.$$

This matrix represents a 4 x 4 matrix. If region *A* would have one more industry it would become a 5 x 5 matrix or if region *B* would have two more industries, it would represent a 6 x 6 industry and so on. Though in these cases more superscripted terms and equations would exist. (Miller & Blair, 2009 pp. 76-80) According to Bachman et al. (2015) another possibility to extending the matrix is by diving a region into sub-regions. In this example by dividing the sub-region *B* into two we would end-up with matrix

$$C = \begin{bmatrix} c^{rr} & c^{rs_1} & c^{rs_2} \\ c^{s_1r} & c^{s_1s_1} & c^{s_1s_2} \\ c^{s_1r} & c^{s_2s_1} & c^{s_2s_2} \end{bmatrix}.$$

In this case the term *A* is replaced by *C* to separate it from the original example and to represent the new trade coefficients matrix. This expansion in turn would require either more detailed data about trade flows between regions or use of coefficients based on assumptions about the polarization of activities in region *B*'s sub-regions. To continue the original case of 4 x 4 matrix it can be conveyed that

$$x = \begin{bmatrix} x^r \\ x^s \end{bmatrix},\ f = \begin{bmatrix} f^r \\ f^s \end{bmatrix},\ I = \begin{bmatrix} I & 0 \\ (2x2) & (2x2) \\ 0 & I \\ (2x2) & (2x2) \end{bmatrix},$$

afterwards of, the equation (6) can be expressed in familiar manner

$$(I - A)x = f, \tag{7}$$

structure of which can be portrayed in this case as

$$\left\{\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} A^{rr} & A^{rs} \\ A^{sr} & A^{ss} \end{bmatrix}\right\}\begin{bmatrix} x^r \\ x^s \end{bmatrix} = \begin{bmatrix} f^r \\ f^s \end{bmatrix},$$

from which it is clear that the needed gross outputs in both regions for the final demand of one or both regions can be found using

$$x = (I - A)^{-1}f. \tag{8}$$

Multiregional input-output tables and models following assume the stability of both inter- and intraregional coefficients meaning that the structure in production and trade is frozen as it does not vary over time (Miller & Blair, 2009 pp. 76-80). In this case the model is also constant at its price, though there exists ways to include price fluctuations (Raa, 2006 p. 17-19) and other parameters. However, the models are more often than not used as static models with constant prices.

MRIO models provide a large scope for analysis than a same-size single-region (2 x 2) models, meaning that they are more accurate representation of the real-world scenarios, but at the same time require more data, connections and assumptions about interregional trade relationships constancy (Miller & Blair, 2009 pp. 76-80). Figure 11 illustrates the interregional spill over effects from the trade relationships that the MRIO model is able to capture – increases in region A's final demand affect outputs of region A directly as well as indirectly thorough output of region B.

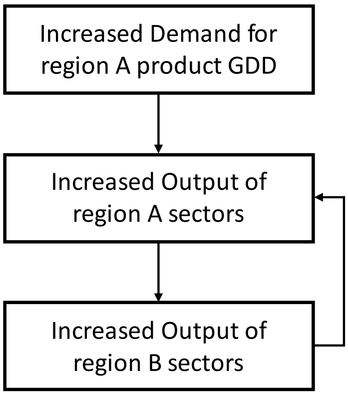

Figure 11. *Interregional spillover effect (adapted from Miller & Blair, 2009 p. 80)*

3.1.3 Global multiregional input-output model

A multiregional input-output model can be further extended to capture the whole global economy. These Global MRIO models capture the essence of global value chains and production networks that can be described as interfirm webs that extend spatially across national boundaries, integrating parts of different national and subnational territories (Lazzarini, 2015) The process of connecting different regions together within a GMRIO is very similar to that described in many-region input-output model, though various harmonization efforts exist and have to be done (Tukker et al., 2018). A simplified version of global multiregional input-output table is presented in figure 12 below.

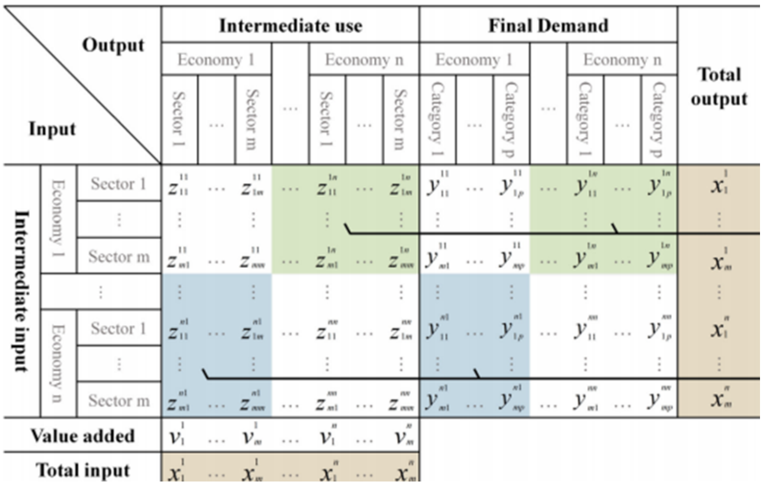

Figure 12. *Global multiregional input-output table (Wang & Qe, 2020)*

The table presented in figure 12 describes the flows of services and goods in global economy between all the industries as well as those provided to the final users (Arto et al. 2019; Wang & Qe, 2020). Instead of describing the world, the MRIO table could as well display a set number of countries or regions within a geographically restricted region, but then the rest of the world economy has to be described with distinct imports and exports or a rest of world (RoW) or rest of economy (RoE) block (Andrew et al., 2019).

This technicality is ambiguous as some globe overing MRIOs are interpreted as international or inter-country IOs and some as GMRIOs though none of the acknowledged GMRIOs capture all the global connections and individual countries. Hence, RoW block is used in global MRIOs to capture whole world to sufficient extent. For a global economy with *n* economies (countries) and *m* sectors (industries), the multiregional input-output table can be abbreviated in block matrix format as Wang & Qe, (2020):

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} \times \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} + \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nn} \end{bmatrix},$$

where x_{ij} is the total output matrix, A_{ij} is the technical coefficients matrix and y_{ij} is the final demand matrix, where the country *i* supplies services and products to country *j*. As the basic linear equation of multiregional input-output models is $x = (I - A)^{-1}f$, this can be abbreviated as world level form of Leontief inverse matrix $L = (I - A)^{-1}$ that describes the dependence of industries overall outputs and demand of the end products

$$x = Ax + y = Ly. \tag{9}$$

To reflect the direct and indirect international trade and technological linkages expression has to be broken into pieces. As x_j^s is the total required input for production activities of sectors *s* in country *j* and z_{rs}^{ij} is the intermediate products that are provided by sector *r* in country *i* to sector *s* in country *j* the element a_{rs}^{ij} of the *A* matrix is provided by

$$a_{rs}^{ij} = \frac{z_{rs}^{ij}}{x_s^j}, \tag{2}$$

and the output from the demand of country *i* based on the MRIO model is expressed as

$$\begin{bmatrix} x_{1i} \\ x_{2i} \\ \vdots \\ x_{ni} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} \begin{bmatrix} x_{1i} \\ x_{2i} \\ \vdots \\ x_{ni} \end{bmatrix} + \begin{bmatrix} y_{1i} \\ y_{2i} \\ \vdots \\ y_{ni} \end{bmatrix},$$

from which the total output (x_i) of country *i* can be derived. It can be further decomposed into outputs respectively incurred by external (x^{ij}) and domestic demand (x^{ii}), according to the accounting standard that is based on the location of final demand

$$x_i = \sum_j x^{ij} = x^{ii} + \sum_{j \neq i} x^{ij}. \tag{10}$$

Only the general expressions on mathematics behind the global MRIO model is portrayed. The mathematical expressions display the connection and scale difference to a *n* region MRIO as the methodologies are similar at their core. For more detailed representation of the GMRIO model and the addition of value-added decomposition, readers should consult Arto et al. (2019).

3.2 Connecting of national and global input-output models

Multiple ways of extending and linking more detailed regional IO models to more extensive ones have been introduced in literature. The operation is done for various reasons, but most of all in order to capture the international spill over effects that the original model is unable to capture, while keeping the structure of original tables intact (Moran et al., 2018). In broad terms, IO-linking approaches can be classified under trade linking, multi-scale integration, supply use transformations, trade and transport margins, closed and hybrid models, though extensions to classifications can mismatch the approaches. Although, trade linking and integration of a foreground country into a MRIO can be seen as the most attractive option for practitioners. (Rodrigues et al., 2016) These approaches tend to either implement a sub-national IO-tables inside an existing GMRIO (Bachman et al., 2015; Christis et al., 2017; Meng et al., 2018; Piñero et al., 2020; Wang et al., 2017; Zhang et al., 2019) or link the whole or parts of the original model to a global MRIO keeping the original IO model intact (Edens et al., 2015; Palm et al., 2019).

Implementing an existing sub-national MRIO model into a global model requires multiple varying steps depending on the initial data which in turn determines if the model is called nested or multi-scale model (MSIO). Usually the monetary units are not the same in the original IO-tables and global MRIOs as these are displayed in USD. Therefore, a conversion has to be done, keeping in mind the base year of the global tables. (Wang et al., 2017) This indirectly introduces the problem of possible differentiation in time horizons of the chosen IO-tables. However, this problem can be bypassed by linking the international trade scales of a nation and its regions according to the existing scales of the nation in a global table, a step which is often taken regardless of timeliness if data about international trade of nations sub-regions is unavailable (Christis et al., 2017). Still, using trade data to rebalance international trade of implemented sub-national IO-tables in the linked MRIO table is advisable instead of using direct proportions based on overall IO-data as it yields more accurate results (Piñero et al., 2020). Finally, the last major step in connecting IO-tables together is matching the classifications of the IO-tables. The procedure can be done with maps and concordance (Bachman et al., 2015; Wang et al., 2017) or coordinate matrices (Meng et al., 2018). These link, combine and balance the classifications based on the original proportions so that scales of data remain unaltered. Despite the methods being able to link different sectoral aggregations and even varying upper classifications (commodity, product, industry or sector) it is not uncommon to aggregate sectors in both initial data tables into a more compact entirety, this being the case for China where the 30-region sub-national IO-tables have been linked to multiple GMRIOs either in 30-sector (Wang et al., 2017; Zhang et al., 2019) or 20-sector (Meng et al., 2018) aggregate. The contraction might be useful if the sectoral classifications between tables mismatch heavily to avoid immoderate data manipulation or if it simply is sufficient detail for desired results as it can reduce the size of the data table massively. Figure 13 demonstrates implementation of subnational input-output table inside of a global MRIO-table.

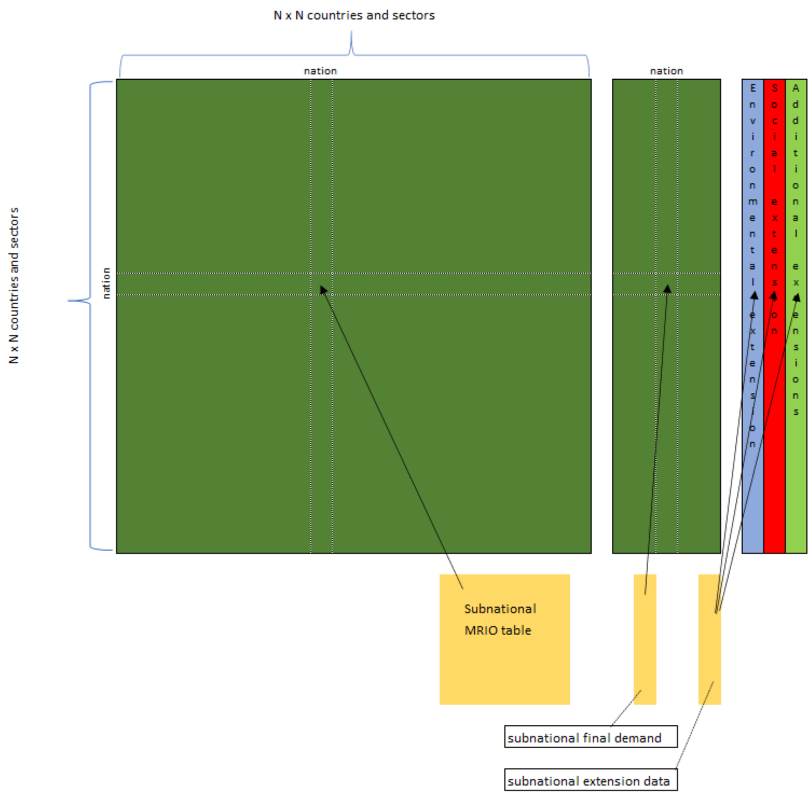

Figure 13. *Inserting of a subnational MRIO table into a global MRIO table (adapted from Meng et al., 2018)*

Often just linking an IO-table onto a GMRIO is more attractive option than implementing it to be a part of it as this usually means less need for manipulation of data and keeping of the original model structure as is. Many of the same steps are still required such as currency conversions and using concordances, but the models can be run somewhat separately meaning that the detail or extensions of local data are not restricted by the GMRIO (Palm et al., 2019). It is also often the best option when analysing impacts of open economies where the harmonization of data might lead into very distorted results (Edens et al., 2015). As the steps taken in connecting the models can heavily differ, these methods are often referred as either SNAC (Edens et al., 2015) or simplified-SNAC

(Palm et al., 2019) approach (single national accounts coefficient). The original SNAC approach prepares a multi-country MRIO in respect to original national IO-table thorough multiple extensive steps (Edens et al., 2015; Moran et al., 2018) whereas the simplified approach simply links the international impacts to national ones via concordance and allows running the modules mostly separately (Palm et al., 2019). Even more straight-forward linking can be done by using coefficients of MRIO model on national model's import vector to account for the international impacts or by simply using a background MRIO to capture the international impacts thorough imports. At simplest form, this methodology is quite easy to implement but can lead into restraining the full potential of the model with procedures like exclusion of indirect international impacts to avoid double counting which influences the magnitude of feedback effects. (Moran et al., 2018)

3.3 Extensions of MRIO analysis

Input-output models can be extended to cover additional accounts whether the base of the model is in physical or monetary terms. These accounts include environmental, socioeconomic and material accounts, and their extensions. This if often done with use of satellite accounting (supplementary statistics of certain field or strand of economy), indicators or coefficients. The drawback of using coefficient approaches is in the fact that they are unable to capture the full nature of global value chains (Tukker et al., 2018). On the other hand, satellite accounts are often directly linkable or adaptable to existing national accounts or SUTs and already available for multiple global MRIOs in form of hybrid or individual tables. The most common extension to MRIO is the environmental extension which can cover anything from emissions and water use to biodiversity, making the model EE-MRIO.

The original form EE-IO is a long-standing technique to evaluate the connection between economic and downstream environmental activities (Kitzes, 2013). In mathematical terms the extension can be used in conjunction with Leontief inverse matrix as Mi et al. (2016) in calculating consumption-based carbon-dioxide emissions

$$C = K(I - A)^{-1}Y^{d} \ , \qquad (11)$$

where C is the vector of total carbon-dioxide emissions embodied in services and goods that is used for final demand, K is the carbon intensity vector for all sectors in the economy, and y^d refers to vector y being diagonalized (Mi et al., 2016). In similar fashion the environmental extension can be applied to MRIO analysis by using block matrix formats or to different accounts by change in output using vectors other to CO_2.

Environmental extensions can be found and used for many national accounts and some of existing global MRIO databases including WIOD, Eora, Exiobase and GTAP (Kitzes, 2013). These extended tables with satellite accounts can be further utilized in conjunction with databases such as the SHDB that can be used for instance with WIODs socio-economic satellite accounts to calculate social risks (Rodríguez-Serrano et al., 2017). Despite the benefits, the extensions are as prone to same mistakes as the traditional IO modelling or even more as differences in aggregation have substantial impact on sustainability results (e.g., baking and producing bread versus growing ingredients to make bread, embedded in same aggregation).

Other extensions and variations of input-output tables include MRIO models extended with economic functions and social accounting matrices (SAMs) that are economy-wide tables that capture all transactions between economic agents in economy (certain time and economy bound) that serve as a base for CGE analyses (Mbanda & Chitiga-Mabugu, 2017; Montaud et al., 2020; Sangare & Maisonnave, 2018). SAMs can also be applied MRIO modelling with CGE conjunction (Nabernegg et al., 2019) though it is very rare. Another extension to MRIO modelling is decomposition which is a technique for global value chain examination with use of MRIOs. It consists of breaking down and observing of different factors from specific industries and countries viewpoint (Arto et al. 2019), enabling the detailed study of individual countries and sectors impacts on others.

3.4 Challenges of MRIO modelling

Multiple input-output databases with global coverage have been introduced to the public (table 4) where steps regarding connection of national exports and imports, double-counting and data harmonization have been carefully considered. However, many challenges and restrictions to be disentangled still exist for the datasets. First, the data in inter-country MRIOs is combined from a variety of data-sources. As the initial databases have differences such as the sectoral aggregation, the data has been clustered or expanded in order to make the tables interconnected. A problem of this procedure is that different classifications can result in different results, especially in footprinting analyses (Piñero et al., 2015). The underlying methodology behind the problem is that in the model an assumption is made that the flows within the classified industries, sectors or commodities are perfectly substitutable to each other (**assumption of homogeneity**). This is obviously not the reality as e.g., under classification of agriculture wheat or fruit serves a different purpose and produces different levels of emissions (Kitzes, 2013). This problem further inflates in the global context as the technologies (and their efficiency) between countries differ which means that at even very disaggregated level the products may be very substitutable (Piñero et al., 2018) e.g., watch made in Switzerland and China differ from both price and the technology used (**problem of domestic technology assumption**).

Second, the **accuracy and timeliness between data sources varies**. The initial datasets used to create the multiregional IO-tables vary in terms of their e.g., data gathering procedures and number of available time-series (Johnson, 2018). As the original data sources of national statistics are usually not available (industry surveys for instance) for the general public, making confirmations about the reliability of the data is challenging. The major issue with timeliness of the data is that tables for some regions are available for certain years and others in another years, as the process of creating IO-compatible data is an extensive process (Kitzes, 2013; Tukker et al., 2018; Wiebe et al., 2018). This in turn means that in order to create uniform timeseries of IO-tables some assumptions have been made. In case of ex-ante evaluation timeliness also affects the results as the present-date data is not available. This means that some fundamental elements such as current technological progress is not properly captured that might be important in terms of results, especially if environmental extensions to the model are considered.

Third, multiregional input-output models do not capture the overall economy truly even if using monetary units as base values as they ignore the externalities and underlying drivers of economy such as unpaid work, financing options, grading of prices, fluctuations or consumption patterns that affect the system in reality (Kitzes, 2013; Tukker et al., 2018). Another issue is the different fees, taxes and margins that are induced on the goods that affect the price composition. However, this problem can be somewhat averted by using uniform prices such as basic or producer prices though some anomalies are evident to occur as the large databases consist of data from multiple different sources.

Lastly, most of the MRIO models are static-demand driven models that cannot capture the over-time accumulating effects (Wiebe et al., 2018). This hinders their usability in long-term investment analysis as the developmental effects of projects or investments cannot be captured within one model run. Simple shocks such as an investment in form of a new production facility can be clearly modelled with rise in the demand for the inputs required to produce the facility but, in the reality, these needs differ throughout the project and should be introduced to the model sequentially. Additionally, when the facility is complete in the future, the operation of it requires different inputs, impact of which has to be separately modelled that is a simulation in different time-boundary. Furthermore, as the starts to feed the economy with outputs, the impact of eating market share from other actors should also be considered, evaluated and simulated.

4. RESEARCH METHODOLOGY

This chapter presents the nature of the research and the methodology followed in this master's thesis. After presenting the research methods the research process itself is unwrapped and the timeline of the study is displayed. Finally, the analysed case is introduced and the result generation process is revealed.

4.1 Research methods

This mono-method quantitative study focuses on constructing a model to evaluate downstream impacts within global value chains. As the research depicts the question "*How to evaluate…*" to solve a real-life matter the underlying research philosophy followed is pragmatism. A further categorization of the research can be clearly made to case-studies as according to Yin (2009, p.18):

> *"Case studies are empirical inquiries that investigate contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."*

Pragmatism implements a variety concepts, research findings and insights in the research process to find optimal solutions to problems at hand. It does not exclude different views or methods to be used in harmonization when undertaking research but rather flourishes the versatility of available approaches. Therefore, pragmatism is natural for research that adopts "cherry-picking" approach to constructing a model or a framework for practical purposes such as this study. Despite acknowledging diverse approaches, using multiple methods is not mandatory for pragmatism as the philosophy emphasizes the diversity of methods in gathering needed knowledge and reliable data. (Saunders et al., 2019 pp. 150-151) Concurrently, in spite of using multitude of statistical and theoretical sources in the process of constructing a model, this research is a mono-method quantitative study as the model itself and the data used in evaluation scenarios is cultivated from publicly available statistics to a uniform form (Saunders et al., 2019 pp. 175-178). The research can also be seen as combined study as it both evaluates the operationality of a model and explains what will happen as a result of set real-life based scenarios (Saunders et al., 2019 pp. 186-188) and some qualitative insights are drawn from the results.

This research adopts a constructive research approach to capture a "snapshot" of impacts following implementation of set scenarios making the time horizon of the study cross-sectional (Saunders et al., 2019 p. 212). Simultaneously an abductive approach is adopted as the research moves back and forth theory and data throughout majority of the research process. By adopting nuances of both inductive and deductive approach, prominent concepts are taken from literature and adapted to suit the existing platforms and case at hand. (Saunders et al., 2019 pp. 152-156) Figure 14 condenses the methodological decisions of the research process.

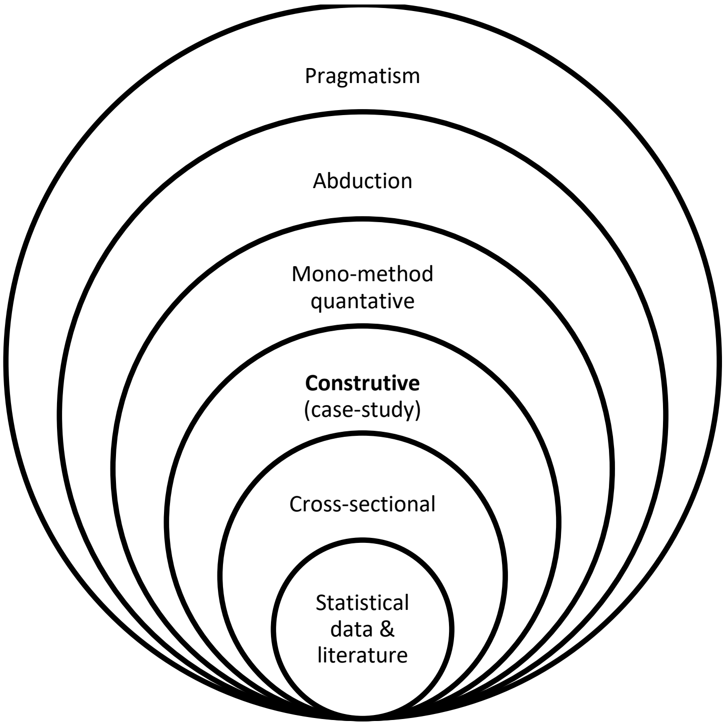

Figure 14. *Methodological choices of the research process (own adaptation of the "research onion" Saunders et al., 2019 p. 174)*

Constructive approach is a sub-category of case-studies that aims to solve real-world problems by creating a construction and scientific contribution in succession (Eriksson & Koistinen, 2005 p. 2; Kasanen et al., 1993; Lukka, 2001). It is a very common approach in technical and business studies as constructions themselves encompass all the man-made models, organizational structures and information systems created – among others – and mold the reality in the process. Constructions can be described as theoretically lead experimental work that aims to demonstrate, test, or refine new theories. (Lukka, 2001) One of the main features constructions is that their usability can be presented with an implementation of a solution (Kasanen et al., 1993). This is a crucial realization as constructions can address phenomena to which adequate benchmark does not yet exist.

Typically, the constructive research process follows six to seven steps beginning with finding practically relevant problem and ending in analyzation of the construction and solution (Kasanen et al., 1993; Lukka, 2001). Though the sequence of the steps may vary by research and -er, implementation of practical approach, clear foundation in scientific literature and critical assessment of the method are necessary steps for successful and reliable execution of the constructive approach (Kasanen et al., 1993). The constructive research process adopted in the study follows Lukka (2001) as displayed in figure 15 below.

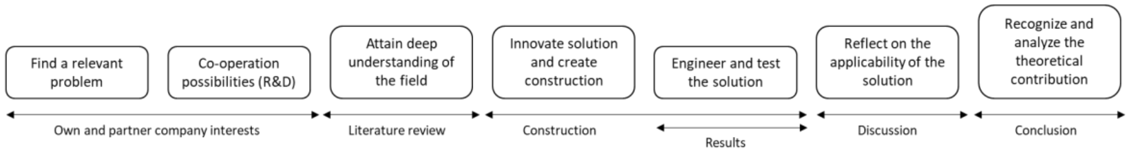

Figure 15. *Constructive research process (adapted from Lukka, 2001)*

Constructive research can achieve both theoretical and practical contribution in multiple ways. Both types of contribution should be addressed with care in pre- and post- execution state (first and last step in the figure 15) and include consideration of relevant factors such as relevance, timeliness, and impact of the research (Whetten, 1989). From a theoretical standpoint, the construction itself can be seen as contributing if it operates successfully in the original case-environment and is able to provide some new knowledge to existing literature. It can also demonstrate the fundamental correlations in the theory and applications thorough its implementation and be used to refine theory. (Lukka, 2001) Naturally, constructions can also bring controversy to the existing theory that it is built on if the solution contradicts with the hypotheses. Lukka (2001) also brings forward that construction can be theoretically contributing even if the project itself would be unsuccessful as reflection on the process can lead into insights on how the precursors should be adapted to find a working solution. Furthermore, even if the construction does not provide sound theoretical contribution, it can become important tool for certain party for practical purposes – e.g., it can be used to solve relevant business problems. However, the process has its pitfalls most common of which are insufficient commitment from one or both of the parties (constructing and receiving), sensitivity of the material produced and fear over trade secrets (especially from theoretical standpoint as this can lead into relevant data not being published) as well as lack of objectivity. (Lukka, 2001)

4.2 Research process

The preliminary research process of the thesis began in January 2021 when talks between the researcher and case-company was held. The preliminary research process included soft familiarization of the research topics around upcoming project including value chains, resource flows, foreign investments, sustainability analysis and circular economy and other others. The initial research questions were finalized during February of 2021 based on the researcher and company interests, and full-steam research process began right after in March. An extensive amount of familiarization to the topic of effectiveness and impact evaluation was done before meeting was held with university professor, case company supervisor and the researcher in mid-March. Following the meeting a clear timeline was set and the scope of the study and initial research questions were slightly adjusted. The realized timeline of the study is captured in figure 16.

A vast literature review was conducted during March and April of 2021 to provide the researcher with sufficient background knowledge in the field to understand the available resources, theory, and current academic discussion to make sound decisions over the to-be construction. The use of headwords began with wide concepts such as *“global value chains”*, *“impact analysis”* and *“effectiveness evaluation”* but were more specifically targeted towards the end of the research process with headwords being in the realm of *“multiregional input-output modelling”*, *“EE-MRIO”* and *“subnational MRIO”* as the field became clearer for the researcher following the critical review process (Saunders et al., 2019 p. 60).

Creating a linkable model was at the core of the research and real work on the construction began in May 2021 after deep understanding of the field and mathematics behind MRIO modelling was accumulated and existing local models of the case company were studied. **A subnational MRIO model with global links and sustainability extensions was created by the end of June 2021 through trial and error and constant dialogue with the models target user group**. After validating the operationality of the model with simple test runs, statistical data for the scenarios was gathered and shaped in the turn of June-July 2021 and the model was ran for results. The results and analysis were done in conjunction and the process was finished by the end of July. These were reflected back on previous literature findings, other analyses with the constructed model and a benchmark to validate the results and to evaluate the operationality of the model. As the evaluation of the method and meeting with models target user group sprang up some additional ideas, minor adjustments were done to the constructed models graphical interface and thesis structure in early August 2021.

After the results, analysis and the method evaluation were completed they were presented to the case company for additional comments. Based on the comments further global value chain analysis was done and some concepts were unwrapped. After the changes, discussions was held with university professors and comments were gatherer, resulting in large amount fine tuning of the thesis’s content, structure and presentation. Finally, by the end of August 2021 after all the necessities were added and nitty-gritty bits of the study were polished, the thesis was finalized.

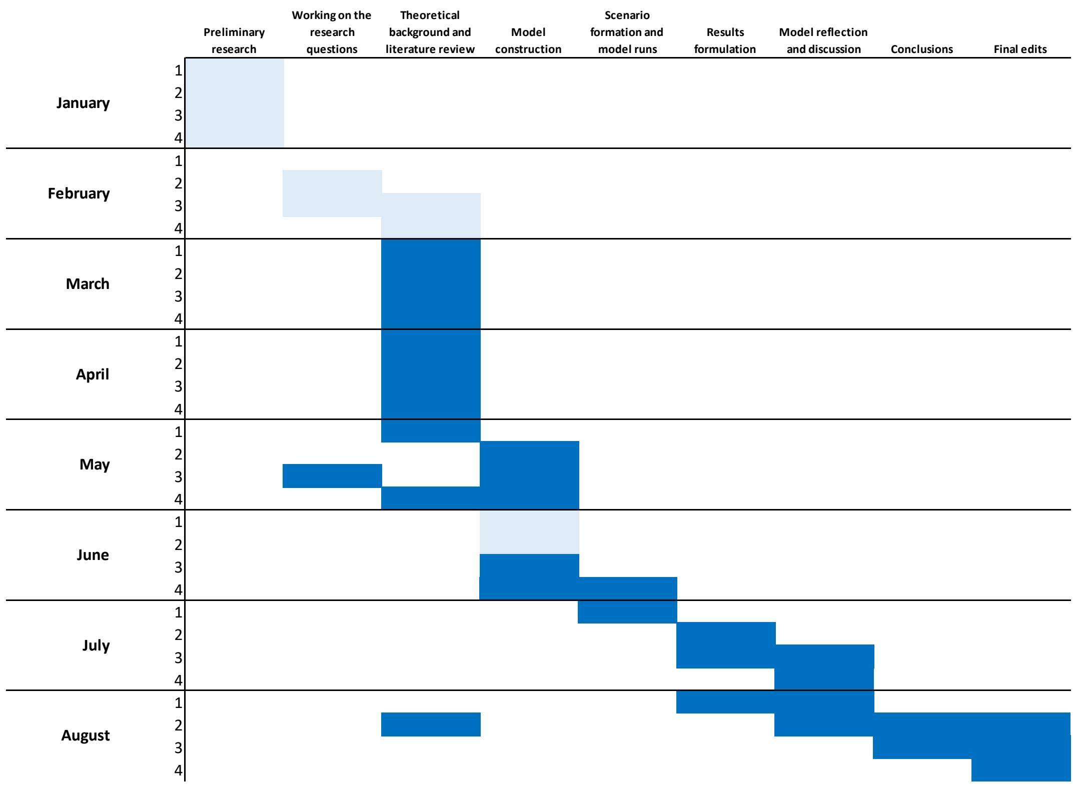

Figure 16. *The timeline of the study*

4.3 Case introduction

4.3.1 European Union Recovery and Resilience Facility

The Recovery and Resilience Facility (later the Facility) is EU distributed financial support to public investments and reforms to its member states to mitigate the impact of covid-19 pandemic and steer the European economy towards more digital and sustainable direction (European Commission, 2021). The case was chosen as it is societally significant, current and enables the capturing of both the global and the downstream impacts of a single country. Thus, it demonstrates the operationality of the construction via implementation of solution (Kasanen et al., 1993) within the scope of the study.

The Facility consists of 672.5 billion euros (2018 prices) of capital accumulated from the financial markets, making it the centrepiece of NextGenerationEU stimulus package. The package is established as **temporary instrument** and has been surrounded by a lot of controversy both on the distribution of support and payments of member states and the claim of being temporary. Despite the future of the instrument being at stake on many occasions the process has proceeded to assessment of national plans and the first grants are to be distributed already within 2021. (European commission, 2021; Karismo & Parviala, 2021; Pilke & Koivisto, 2021). The structure of the stimulus package is displayed in figure 17 below.

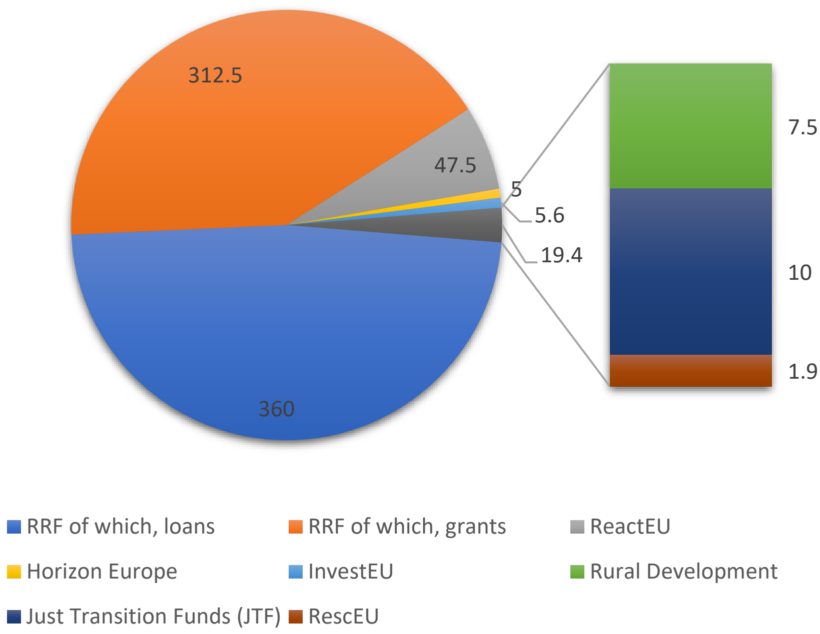

Figure 17. *NextGenerationEU stimulus package in 2018 prices (in billion euros)*

The package is aimed for reforms and investments that create jobs and growth within EU with focus on green and digital economy. Therefore, the national plans to receive the grants are bound to direct a minimum 37 % of the investments and reforms towards climate and 20 % towards digital transformation (European Commission, 2021), though many countries have chosen to direct considerably more on these areas (Darvas et al., 2021). The focus is compartmentalized under seven flagship areas:

1. Clean technologies and renewables (Power up)
2. Energy efficiency of buildings (Renovate)
3. Sustainable transport and charging stations (Recharge and refuel)
4. Roll-out of rapid broadband services (Connect)
5. Digitalisation of public administration (Modernise)
6. Data cloud capacities and sustainable processors (Scale-up)
7. Education and training to support digital skills (Reskill and upskill)

The focal point of the case-scenario analysis is the grants of the Facility, consisting of 338.5 billion euros at current prices (312.5 billion in 2018 prices) distributed among EU members. The financial support is distributed in two steps, first based on unemployment rates of 2015-2019, inverse GDP per capita and population share (218.75 billion euros during 2021-2022) and 93.75 billion euros during 2023 allocated based on drop in real

GDP over 2020, overall drop in real GDP 2020-2021, inverse GDP per capita and population share. (European Commission, 2021). Therefore, the final distribution of grants is not yet set in stone and may change for the second allocation. **The allocation of grants at turn of July 2021 at current prices is used for the scenario in this thesis and can be found in appendix C.**

Finland is about to receive 2.1 billion euros total as of July 2021. The sum has steadily gone down as it was estimated to be around 2.7 billion euros in January 2021 and even more before that (Ministry of Finance Finland, 2021) and naturally it has raised a lot of concerns and discussion. As Finland is a net-payer of the NextGenerationEU grants, having to pay estimated 6.6 billion euros at 2018 prices during 2028-2058 of the 390 billion euros, the Facility split views of both citizens and politicians, and even the Finnish vote to accept the funding scheme barely went thorough after many governmental talks (Pilke & Koivisto, 2021). In spite of the vast difference of 4.5 billion euros it is stated that Finland will benefit from the total package as the total European economy becomes more competitive globally as export industry is vital for Finland (Ministry of Finance Finland, 2021). **Results of this thesis shed light on the direct and indirect downstream impacts that result from the allocated grants (338.5 billion euros at current prices) on Finnish economy at an industrial and regional level** and therefore help understand if the Facility was the right choice for Finland. However, the scenario is static and limited to investment phase (2021-2023) impacts and should not be seen as absolute representation of all the impact by any means.

4.3.2 Data collection

Data for the Facility scenarios was compiled with a three-step process. **First, data sources were researched and data was gathered from multiple** locations. Second, the gathered data was cross-referenced within the found sources **and data was calculated for a few missing economies based on reference countries**. All of the data was initially classified under 19 sectors (18 individual and 1 uncategorized category). **Third, data was converted to the 56-industry classification of the operating models global element** (WIOD 2016 release classification) based on the sub-industry shares of national industry outputs in the WIOT 2014 (Timmer et al., 2016) as majority of the nation's investments and reforms overlapped industries.

The initial data was gathered from Bruegel datasets (Darvas et al., 2021) for 14 nations that data was available in the 19-sector NACE-classification. For rest of the countries national recovery and resilience plans and related factsheets were consulted (see European Commission, 2021). In the cases where comprehensive summaries were unavailable and language barriers were crossed external summaries was used (Bankwatchnetwork CEE, 2021; European Data Journalism Network, 2021; Karismo & Parviala, 2021; Schuman Associates, 2021). Where the plans did not exist (the Netherlands and Malta), were time-wise too arduous to depict or summaries did not meet the desired standard (Romania and Sweden), calculations were made. The calculations were based on allocations of nearby similar countries and the shares were distributed based on adapted-PESTEL comparison for industry coefficients. The reference countries utilized for calculations are displayed in table 8.

Table 8. *Grant allocations made based on reference countries*

Country in question	Reference countries	Total grants (billion euros)
The Netherlands	Belgium, France, Germany	6.0
Malta	Cyprus, Italy	0.3
Romania	Bulgaria, Hungary	14.2
Sweden	Finland, Denmark, Germany	3.3

After assembling all national data, the uncategorized data was allocated to rest of the sectors based on existing reform distribution and additional details. This was followed by removing of the loan amounts from the Bruegel data (Darvas et al., 2021) as in the scenario only grants were to be examined. However, in reality, the loans granted will have an additional positive impact to the overall and Finnish economy as they have to be only backed in the case that the nation that requests them cannot clear them by themselves (European Commission, 2021; Ministry of Finance Finland, 2021). Finally, the investments were divided to the 56-industry classification and the initial data was complete.

National plans did not exist for all the EU-27 countries and only part of the existing plans were accepted at the time of the scenario analysis (turn of July 2021). Therefore, changes to the industry distribution of investments are evident. Even in the case of accepted plans, many of the planned spending were at upper level and will be later allocated to more specific investments (e.g., “investments to support SMEs”). Hence, waterproof conclusions about the real allocation of the investments could not be drawn from the national plans, albeit they serve as a good basis for effectiveness evaluation in this case.

4.3.3 Data processing

The scenarios were ran thorough constructed model (see chapter 6) with data on all of the EU-27 countries (see appendix 5) individually and altogether. The investments were rolled on with current prices for the total of the investment both the first 70 % of the investments and the to-be adjusted 30%. This means that the total grant amounts simulated mount to 338.5 billion euros for the total scenario and 336.4 billion euros for the scenarios excluding Finnish grants.

Individual runs demonstrate what potential changes are more beneficial for the Finnish economy in comparison to others, giving implications on potential effects of the 30% of investment allocation to-be decided later. Total impacts display the overall downstream impacts on Finland – grants rolled to all of the EU-27 countries besides Finland – at the level of five major regions and the individual sectors most impacted. Supporting results were also drawn on international, EU-27 and rest of the world level for comparison as Finland is not the net-beneficiary of the project. The individual main parameters taken out from the scenario runs are displayed in figure 18.

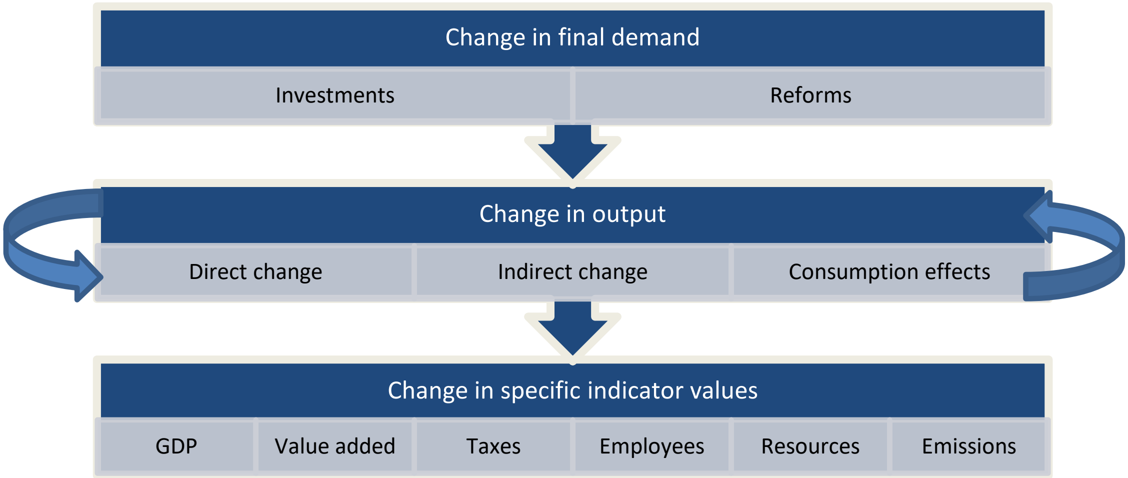

Figure 18. *Simplified representation of the result generation process*

Finland is only recipient of around 0.60 % of the grant funds, denoting that straightforward conclusions about success of investment impacts cannot be drawn as is. Therefore, Finnish indicators are benchmarked to distinct countries in terms of indicator changes per grants received to truly address the environmental and social benefits of the reforms (instinctively one euro of investments in Romania creates more employment than one euro in Finland). Another concern to be addressed was the aggregation between model and initial scenario data. To address this, a sensitivity analysis was conducted based on slight adjustments in actual grant allocations. Before this, the performance of different Finnish major regions was measured in comparison to each other to evaluate the subnational value chains and whether the instrument favours thriving highly-populated areas or fosters uniform development.

5. MODEL CONSTRUCTION

An environmentally extended MRIO model with subnational coverage was created for the purposes of this study. The MRIO model was built on most recent WIOD data (Timmer et al., 2015; 2016) and further connected to an existing subnational model of Ramboll (based on most recent Finnish state of economy and industrial interactions data) with multiple adjustments and connections having to be made to both models throughout the process. The core connections of the linked model resemble the work done by Palm et al. (2019) with Exiobase, but the model itself varies by operationality, introducing feedback, price and consumption effects, making it more multi-layered and complex. Furthermore, it captures the triple bottom line impacts thorough its environmental and social extensions built from official WIOD (Genty, 2012; Timmer et al., 2015) and JRC (Corsatea et al., 2019) statistics. Overall, the construction process comprised of:

1. Choosing the base model by getting familiar with different GMRIOs
2. Creating a simple WIOD based MRIO model
3. Creating concordances to connect the model to the two-region subnational model
4. Linking the models together with trade connections
5. Creating and linking the environmental and social extensions of the model
6. Implementing consumption effects into the model
7. Connecting the model to even more detailed subnational-MRIO
8. Implementing price elasticities of demands to Finnish side of the model
9. Creating simple macros to run the model and visualizations to present the results
10. Running the model for the final results

5.1 Construction process

5.1.1 Building of model foundation

The paramount choice in building of the model was choosing the global MRIO to build it on as global EE-MRIO was recognized as the optimal solution during literature review process. During that process, the major global MRIOs were also recognized and further analysis on the applicability of the databases was conducted before choosing WIOD as the base data for the linked model. World input-output database was chosen due to the transparency of its building process based on official national accounts and trade data (Timmer et al., 2015), its existing social and environmental extension data, it being utilized by both international and Finnish governmental organizations and its moderate size. **The construction process was done in a manner that similar methods could be followed to create comparable models based on other databases as well** (e.g. by OECD) though it would still require a lot of work. The WIOD database also covers all of the Finland's major trading partners that constitute over 90% of Finnish trade according to statistics by Finnish Customs (2019) which was prerequisite for the base GMRIO as the main purpose of the current model is to capture the Finnish impacts. Table 9 displays the 43 individual countries within WIOD alphabetically (RoW region excluded) and the top 43 exporting and importing countries of Finland by monetary value.

Table 9. *Top trading partners of Finland and the WIOD regions (based on Finnish customs, 2019 and Timmer et al., 2016)*

WIOD	Exports	Imports
Australia	Germany	Germany
Austria	Sweden	Russia
Belgium	USA	Sweden
Bulgaria	Netherlands	China
Brazil	China	Netherlands
Canada	Russia	USA
Switzerland	United Kingdom	Poland
China	Belgium	Estonia
Cyprus	France	France
Czech Republic	Estonia	Norway
Germany	Poland	United Kingdom
Denmark	Norway	Italy
Spain	Italy	Denmark
Estonia	Japan	Belgium
Finland	Denmark	Spain

France	Spain	Czech Republic
United Kingdom	South Korea	South Korea
Greece	Turkey	Japan
Croatia	Switzerland	Congo (Democratic Rep.)
Hungary	Canada	Austria
Indonesia	Australia	Switzerland
India	Latvia	Canada
Ireland	Lithuania	Brazil
Italy	India	Turkey
Japan	Mexico	Ireland
South Korea	High seas	Lithuania
Lithuania	Austria	Hungary
Luxembourg	Egypt	India
Latvia	Morocco	Taiwan
Mexico	Indonesia	Portugal
Malta	Czech Republic	Slovakia
Netherlands	Brazil	Vietnam
Norway	Special country code	Latvia
Poland	Hungary	Malaysia
Portugal	South Africa	Chile
Romania	Chile	Romania
Russia	Arab Emirates	Mexico
Slovakia	Taiwan	Thailand
Slovenia	Ukraine	Hong Kong
Sweden	Thailand	Greece

Turkey	Portugal	Singapore
Taiwan	Singapore	Indonesia
USA	Saudi Arabia	Bangladesh

After choosing WIOD as the base for the model, required datasets were gathered from the official WIOD site and the subnational-MRIO was further studied. The basic-GMRIO model was created on WIOT2014 by following the mathematical expressions presented in the third chapter. In written form the procedure follows four steps:

1. *Creating the A-matrix by dividing the full Z-matrix with output vector*
2. *Creating identity matrix and deducting the A-matrix from it*
3. *Creating the Leontief inverse matrix from the new matrix*
4. *Linking the Leontief inverse and changes in final demand to changes in output*

Spreadsheet computation software was used for the calculations as WIOTs basic global tables comprise of over 6 million different values. As this already requires some computational capacity specialized software is recommended to be used when dealing with even larger datasets such as Exiobase version 3.

5.1.2 Linking of regional modules

In order to link the Finnish MRIO to WIOD concordances (later sector-keys) had to be made in order to match the differing classifications between models as the Finnish model uses either TOL63 or TOL67 sector classification and WIOD classification comprises of 56 industries. The sector-keys are in place to keep the original structure of the linked models intact to avoid manipulation of original data as much as possible in resembling fashion to the concordance or coordinate matrices and vectors used in literature (Bachmann et al., 2015; Meng et al., 2018; Wang et al., 2017). The impact of designer choice on sector keys was minimized by using value distributions of the original models and more precise official trade data when classifications were matched. **Table 10 displays the differing sectoral classifications between global and Finnish module within the constructed model and their connections circulating in the model.**

Table 10. *Different classifications in the constructed model*

TOL63	TOL67	WIOD
01 Crop and animal production, hunting and related service activities	01 Crop and animal production, hunting and related service activities	Crop and animal production, hunting and related service activities

02_03 Forestry and fishing	02_03 Forestry and fishing	Forestry and logging
		Fishing and aquaculture
05_09 Mining and quarrying	05_09 Mining and quarrying	Mining and quarrying
10 Manufacture of food products	10 Manufacture of food products	Manufacture of food products, beverages and tobacco products
11_12 Manufacture of beverages and tobacco products	11_12 Manufacture of beverages and tobacco products	
13_15 Manufacture of textiles, wearing apparel and leather products	13_15 Manufacture of textiles, wearing apparel and leather products	Manufacture of textiles, wearing apparel and leather products
16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
17 Manufacture of paper and paper products	17 Manufacture of paper and paper products	Manufacture of paper and paper products
18 Printing and reproduction of recorded media	18 Printing and reproduction of recorded media	Printing and reproduction of recorded media
19_21 Manufacture of coke and refined petroleum products, chemicals and chemical products, basic pharmaceutical products and pharmaceutical preparations	19_21 Manufacture of coke and refined petroleum products, chemicals and chemical products, basic pharmaceutical products and pharmaceutical preparations	Manufacture of coke and refined petroleum products
		Manufacture of chemicals and chemical products
		Manufacture of basic pharmaceutical products and pharmaceutical preparations
22 Manufacture of rubber and plastic products	22 Manufacture of rubber and plastic products	Manufacture of rubber and plastic products
23 Manufacture of other non-metallic mineral products	23 Manufacture of other non-metallic mineral products	Manufacture of other non-metallic mineral products

24 Manufacture of basic metals	24 Manufacture of basic metals	Manufacture of basic metals
25 Manufacture of fabricated metal products, except machinery and equipment	25 Manufacture of fabricated metal products, except machinery and equipment	Manufacture of fabricated metal products, except machinery and equipment
26 Manufacture of computer, electronic and optical products	26 Manufacture of computer, electronic and optical products	Manufacture of computer, electronic and optical products
27 Manufacture of electrical equipment	27 Manufacture of electrical equipment	Manufacture of electrical equipment
28 Manufacture of machinery and equipment n.e.c.	28 Manufacture of machinery and equipment n.e.c.	Manufacture of machinery and equipment n.e.c.
29_30 Manufacture of motor vehicles, trailers, semi-trailers and other transport equipment	29_30 Manufacture of motor vehicles, trailers, semi-trailers and other transport equipment	Manufacture of motor vehicles, trailers and semi-trailers
		Manufacture of other transport equipment
31_32 Other manufacturing, including furniture	31_32 Other manufacturing, including furniture	Manufacture of furniture; other manufacturing
33 Repair and installation of machinery and equipment	33 Repair and installation of machinery and equipment	Repair and installation of machinery and equipment
35 Electricity, gas, steam and air conditioning supply	35 Electricity, gas, steam and air conditioning supply	Electricity, gas, steam and air conditioning supply
36_39 Water supply; sewerage, waste management and remediation activities	36_39 Water supply; sewerage, waste management and remediation activities	Water collection, treatment and supply
		Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
41+432_439 Construction of buildings &c.	41+432_439 Construction of buildings &c.	Construction
42+431 Water and land construction &c.	42+431 Water and land construction &c.	

45 Wholesale and retail trade and repair of motor vehicles and motorcycles	45 Wholesale and retail trade and repair of motor vehicles and motorcycles	Wholesale and retail trade and repair of motor vehicles and motorcycles
46 Wholesale trade, except of motor vehicles and motorcycles	46 Wholesale trade, except of motor vehicles and motorcycles	Wholesale trade, except of motor vehicles and motorcycles
47 Retail trade, except of motor vehicles and motorcycles	47 Retail trade, except of motor vehicles and motorcycles	Retail trade, except of motor vehicles and motorcycles
49 Land transport and transport via pipelines	491_492 Rail transport	Land transport and transport via pipelines
	4931+4393 Urban, suburban and other passenger land transport n.e.c.	
	4932 Taxi operation	
	494 Freight transport by road and removal services	
50_51 Water and air transport	50 Water transport	Water transport
	51 Air transport	Air transport
52_53 Warehousing and support activities for transportation, postal and courier activities	52_53 Warehousing and support activities for transportation, postal and courier activities	Warehousing and support activities for transportation
		Postal and courier activities
55 Accommodation	55 Accommodation	Accommodation and food service activities
56 Food and beverage service activities	56 Food and beverage service activities	
58 Publishing activities	58 Publishing activities	Publishing activities
59_60 Motion picture, video and television programme production, sound recording and music publishing activities, programming and broadcasting activities	59_60 Motion picture, video and television programme production, sound recording and music publishing activities, programming and broadcasting activities	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities

61 Telecommunications	61 Telecommunications	Telecommunications
62_63 Computer programming, consultancy and related activities, information service activities	62_63 Computer programming, consultancy and related activities, information service activities	Computer programming, consultancy and related activities; information service activities
64 Financial service activities, except insurance and pension funding	64 Financial service activities, except insurance and pension funding	Financial service activities, except insurance and pension funding
65_66 Insurance, reinsurance and pension funding, except compulsory social security, activities auxiliary to financial services and insurance activities	65_66 Insurance, reinsurance and pension funding, except compulsory social security, activities auxiliary to financial services and insurance activities	Insurance, reinsurance and pension funding, except compulsory social security Activities auxiliary to financial services and insurance activities
681+68209+683 Other real estate activities	681+68209+683 Other real estate activities	Real estate activities
68201_68202 Renting and operating of own or leased real estate	68201_68202 Renting and operating of own or leased real estate	
69 Legal and accounting activities	69 Legal and accounting activities	Legal and accounting activities; activities of head offices; management consultancy activities
70 Activities of head offices; management consultancy activities	70 Activities of head offices; management consultancy activities	
71 Architectural and engineering activities; technical testing and analysis	71 Architectural and engineering activities; technical testing and analysis	Architectural and engineering activities; technical testing and analysis
72 Scientific research and development	72 Scientific research and development	Scientific research and development
73 Advertising and market research	73 Advertising and market research	Advertising and market research
74 Other professional, scientific and technical activities	74 Other professional, scientific and technical activities	Other professional, scientific and technical activities; veterinary activities
75 Veterinary activities	75 Veterinary activities	

77 Rental and leasing activities	77 Rental and leasing activities	Administrative and support service activities
78 Employment activities	78 Employment activities	
79 Travel agency, tour operator and other reservation service and related activities	79 Travel agency, tour operator and other reservation service and related activities	
80 Security and investigation activities	80 Security and investigation activities	
81 Services to buildings and landscape activities	81 Services to buildings and landscape activities	
82 Office administrative, office support and other business support activities	82 Office administrative, office support and other business support activities	
84 Public administration and defence; compulsory social security	84 Public administration and defence; compulsory social security	Public administration and defence; compulsory social security
85 Education	85 Education	Education
86 Human health activities	86 Human health activities	Human health and social work activities
87_88 Residential care activities and social work activities without accommodation	87_88 Residential care activities and social work activities without accommodation	
90_92 Arts, entertainment, cultural and gambling activities	90_92 Arts, entertainment, cultural and gambling activities	Other service activities
93 Sports activities and amusement and recreation activities	93 Sports activities and amusement and recreation activities	
94 Activities of membership organisations	94 Activities of membership organisations	
95 Repair of computers and personal and household goods	95 Repair of computers and personal and household goods	

96 Other personal service activities	96 Other personal service activities	
97_98 Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	97_98 Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
		Activities of extraterritorial organizations and bodies

In table 10 the differing sectoral classifications between the Finnish and global module are marked with either green (TOL) or red (WIOD). As seen in the table, 8 overlaps exist on the Finnish (TOL67) classifications to the WIOD classification in the model and a 10 overlaps the other way around. The only differences between TOL67 and TOL63 sectoral classification within Finnish submodules are found within the transportation sectors 49-51. **These differences within classification can cause anomalies on results in spite of being based on official trade data and distributions within original model data.**

First in the linking process, the two modules were linked to capture the global effects of Finnish imports. This was done by connecting the import needs of Finland to the final demand block of demand-driven WIOD-module with sector-keys in place. The process itself was made to be simple and automatic, but the impacts circulating to Finland had to be removed from the import needs as Finland is part of the original WIOD-module to avoid double-counting. *The detailed Finnish model runs by itself without alterations to it, as the Finnish share of the WIOD total is less than 0.5 %.* This was manufactured by calculating a coefficient distribution of Finnish intermediate demand from the WIOT excluding Finland to be fed into the demand vector of WIOD-side of the model. Instead of the described ”random” distribution a more direct import distribution was also calculated so that the model could be used to evaluate investments where part of the import location distribution was already known. This function becomes very relevant in the cases where the import distribution is known to be e.g., third from Sweden, third from Russia and rest is unknown as **the back-home effects vary significantly between countries**.

Much like imports, distribution coefficients had to be calculated for exports as well so that Finnish effects could be captured within the domain of respective models with use of sector-keys. Inherently, here direct exports are captured by altered final demands of industries. These were formed with WIOTs final demand matrices and enable the separation of direct and indirect impacts also on countries besides Finland on a 56-industry level. Aside from using this distribution, exports can naturally be targeted directly to set sectors of countries as it is the basic form of the original WIOD model.

Finally, connection to link the results of indirect and feedback effects from the linked modules to one and other was introduced. These are a part of both of the base models but required distinct connections from WIOD-side back to the Finnish model to again avoid double-counting. Although Moran et al. (2018) establishes that feedback effects are usually no larger than couple of percentage points, they were introduced to the constructed model for maximum accuracy.

Consumption effects were initially only part of the Finnish side of the model, but they were additionally calculated and introduced into the global side of the model to provide more realistic global scenarios. They are derived from the social extensions employee compensation results (chapter 5.1.3.) and iteration loops are used to capture the full consumption effect. These values are not taken directly from this vector as all of the employee compensation is not spent or in some cases even more of it is spent (impact of loans, grey economy, multiplicative effect). Instead, coefficients for country-specific consumptions were calculated based on individual countries WIOD expenditure by household and compensation data (Timmer et al., 2015), and these were balanced with accurately approximated Finnish compensation-to-spending coefficient.

5.1.3 Connection of sustainability extensions

The linked-MRIO model was extended to cover sustainability effects with use of satellite accounting. This was done by calculating the corresponding environmental and social indicator vectors from official statistics on environmental and social impacts by country, publicly available on the WIOD website (Genty, 2012; Timmer et al., 2015). For the updated environmental values on energy and carbon dioxide impacts, official datasets provided by JRC of EU Commission were used (Corsatea et al., 2019). Only these official databases were used to keep transparency at maximum. However, for maximum accuracy the coefficients should be calculated based on most recent official national data for each country which is in turn very time-consuming process.

The assembled extensions were connected on the change of output in the global model and operates with the logic presented in mathematical expression 11 as the core result generation processes are bound to changes in outputs in the model. These extensions cover as many individual environmental indicators as possible within the limits of used official data, to capture the impacts at maximum detail and to be extendable to cover multiple sustainability indicators in future. Table 11 presents the upper-level indicators of the model, the detailed indicators can be found in appendix B.

Table 11. *Environmental and social extensions of the constructed model*

Indicator	Reference
Energy use	Corsatea et al., 2019
Carbon dioxide	Corsatea et al., 2019
Emissions	Genty, 2012
Material, land and water use	Genty, 2012
Social impacts	Timmer et al., 2015

Official extension data is not available for all industries nor countries (mainly rest of the world region) which may lead in slightly lesser simulation results in comparison to real-life situation in terms of total environmental and social impacts. However, most of these exclusions are a result of set industry having close to none direct impact on the matter, e.g. other industries amount of land use in comparison to agriculture and forestry industries land use, of which the accounts only exists for, with a possible deviant of housing industry affecting the parameter by clearly limiting the available land. This analogy is intelligible as the land use indicator accounts for the land area used by economic activities – land is used but not consumed as such in comparison to e.g., materials which refer to extracted resources that enter the system for direct consumption or further processing. (Genty, 2012)

Similar to land use, the material accounts only exist for the primary activities that extract these materials (classification 1-9) as manufacturing and service industries use these commodities but do not extract them themselves. Furthermore, same sentiment partly applies to the indicator of water use as it covers the virtual water flows (further descriptions of individual water indicators in chapter 7.2.2.). and therefore encompasses only a part of the industries by e.g., disregarding the transportation industry totally. Energy, carbon dioxide and emissions (air pollutants) on the other hand cover all of the available industries as they all clearly contribute on the matter on their respective accounts and help assess the categorized and sectoral global warming, acidification and ozone formation impacts related to ventures. (Genty, 2012) What's more, the energy use is captured as both gross energy use and emission relevant energy use. However, there are debates over the exact nature of the energy accounts in international community, that the extensions are built from, though they are part of the economy-wide material flow accounts by compilation process (Corsatea et al., 2019). Hence, the usability of the energy extension can be restricted by case at hand.

Compared to environmental indicators social ones are more straightforward as they are derived from much of the same national and other statistics as WIOD (Timmer et al., 2016) and contribute to the model with indicators (work hours, years and labour compensation) bound to output. Other social indicators besides the introduces ones (appendix B) could be covered by the model, calculated directly from existing social data such as changes in capital compensation. However, these additional accounts were deemed unnecessary additions to the model for the time being.

5.1.4 Finalization of the model

After the core and connections of the model were completed, a static functionality for calculating the effects that price changes have on final demand was added to the Finnish side of the model. This functionality is based on price elasticities of demand which were calculated based on statistics by Statistics Finland (2021) on manufacturing and related industries, Natural Resources Institute Finland (2021) on agriculture, hunting, forestry and fishing, and the OECD (2021) on services, trade and other industries. The price-elasticities were calculated as averages of available time-series and compared to values found in literature. The calculated values that had large anomalies were excluded from the averages and in some cases average values found in literature were used as is or as a combined average with the calculated values if the sources were deemed reliable and more accurate than researchers own calculations.

After the addition of price elasticities, the model was finalized by creating various counters for different results (e.g. direct changes, changes by industry and country, changes by group of industries, environmental impacts) to which visualizations were added. Lastly, few macros were made in place to act as either scenario clearers or to move some intermediate results from one location to another when heavy iterations were to be avoided. Figure 20 represents one of the many interactive visualizations of the model.

5.2 Model operationality and global value chain analysis tests

The model operates by introducing change in final demand of a sector of a country to the model – final demand input in the figure 19. This denotes that **currently the model can be used to evaluate impacts of change as a snapshot**. *In case of the Facility grants this means that the changes of the investment phase (2021-2023, roughly 112 to 113 billion euros of investments per year) need to be modelled separately from the post-investment phase as the investments have most-likely an impact on the operating environment and therefore adjusted matrices for intermediate goods, environment etc. should be used for the post-scenario*. When the change is introduced into the model, it is distributed as direct impacts to different sectors. This in turn introduces intermediate demand which introduces more intermediate demand and so on. At the same time consumption effects take place by introducing similar final and intermediate demand chains to the model. Finally, the model runs realize as change in sectoral outputs which are linked to the economic, environmental and social extensions of the model that display majority of the sustainability impacts in the case. Mathematically the main process is covered in chapter 3 and the simplified version of the constructed model with module-links is displayed in figure 19 below.

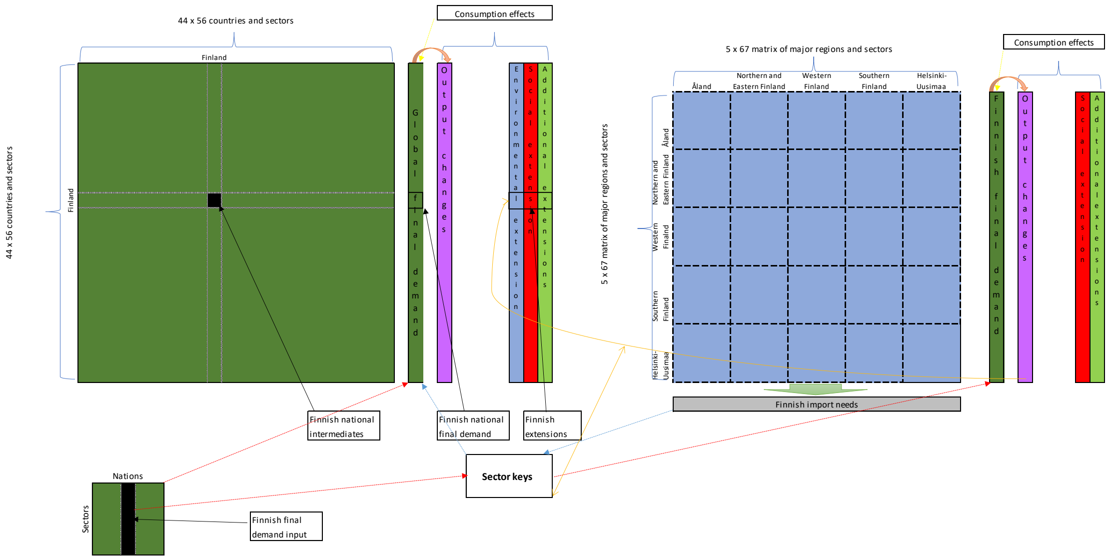

Figure 19. *Simplified representation of the construction, a GMRIO model*

Numerous tests were run with the model throughout the process, ranging from single Finnish investments to combinations of international ones to ensure its correct functionality. After the completion of the model but before implementation of solution final test runs with the model were ran in order to find out the most attractive locations for Finnish foreign investments. The runs consisted of evenly spread investments to all the sectors of a single country and captured the direct, indirect and consumption impacts related to these investments. The results of these runs are presented in table 12 below.

Table 12. *The most attractive options for Finnish backed foreign investments*

Total of all sectors	***Manufacturing and primary prod.***	***Services, trade, and others***
EST	EST	EST
SWE	SWE	SWE
LVA	LVA	LVA
LTU	NOR	LTU
NOR	LTU	RUS
RUS	DNK	NOR
DNK	SVK	IDN

SVK	RUS	DNK
IDN	BEL	CAN
BEL	NLD	CHE
NLD	DEU	NLD
POL	POL	POL
DEU	GBR	BEL
CHE	IRL	CYP
GBR	HUN	DEU
CAN	CHE	CHN
AUT	IDN	AUT
HUN	CZE	JPN
LUX	LUX	MLT
CYP	AUT	LUX
CZE	FRA	TUR
TUR	TUR	ROW
FRA	BGR	AUS
BGR	ITA	HUN
MLT	ESP	GBR
ESP	CYP	CZE
ITA	ROU	BGR
JPN	HRV	SVN
ROW	PRT	FRA
HRV	GRC	KOR
AUS	MLT	SVK
KOR	KOR	IND
ROU	ROW	HRV
CHN	CAN	ESP
GRC	AUS	ITA
PRT	JPN	ROU
SVN	SVN	GRC
IND	TWN	PRT
TWN	USA	BRA
BRA	CHN	MEX
USA	MEX	TWN
MEX	BRA	USA
IRL	IND	IRL

Main finding from the table 12 is that around 20 % worth of output of the initial investments in Estonia circulates to Finland, making it the most prominent foreign investments location and trading partner based on statistically distributed global value chain impacts. The second and third best options, Sweden & Latvia, lag behind at around 10 %. The second major finding from the table 12 is that only a small percentage of the initial investments value finds its way to Finland when investments are rolled on to some of Finland's main trading partners economies, namely China, France, and the US, when comparing the results to findings in table 9. Lastly, another relevant factor of the table – that does not always realize in the actual environment – is the negative impacts that certain nations particular industries have on Finnish economy (decrease of demand for Finnish goods). This realizes clearly in the case of Ireland where investments made in manufacturing industries have a significant positive effect to the Finnish industries but investments in service industries have a notable negative impact to the total Finnish impacts. **The test run of table 12 serves as good overall indication for optimizing Finnish funded foreign investments and is reflected on the Facility scenario in 6.3.3.**

5.3 Restrictions of the model

The model can be used to create accurate ex-ante evaluations of potential changes to economy as long as the data values fed into the model are accurate and validated estimates. However, much like any other GMRIO **the constructed model has its restrictions, namely sectoral aggregation, data harmonization procedures taken in creating initial datasets and timeliness** (see chapter 3.4). The datasets the model is built on are **based on historical data** which has to be considered when analysing the results, though in most cases 5-10 years old base data is fine in this type of economic and environmental assessments due to **speed of technological change**. The clear issue that comes up with models based on outputs (monetary) after – and during – the time period is that **technological progress, especially in terms of material use, environmental impacts and employee costs, does not follow the same development pattern as outputs** as technological progress allows the cutting down of impacts such as emissions even if the amount of production stays the same. *Hence, for superior estimates on environmental impacts, a model with material core should be used instead of monetary one as monetary impacts can be lead from up-to-date price charts*. Another time-effect to be considered when analysing specific results is the state of sectors and large firms at the time-being and at time of the base data. This becomes very relevant in the case of Finland when using old data as e.g. Nokia’s impact on economy and set sectors used to be massive way-back.

Aggregation can cause clear analytical hindrance in two ways in this case. First, as the sectors are aggregated in the model, the impacts are distributed based on averages to other sectors by the aggregated sector. In practice, this means that the impacts of different sub-sectors are not captured to the best extent as different sub-sectors can have varying value chains in reality. Consequently, the other drawback is that the **final impacts cannot be directed to sub-sectors without further value chain mapping** based on external information. Lastly, the model does not directly account for the **value of money** which should be considered when modelling change that is distributed over multiple years. This is an externality that has to be calculated by the operator before entering the inputs to the model. Additionally, in these cases the environmental impacts have to be based on the original values as **technological progress is not expected to follow the same rate of change as value of money**, ergo two separate model runs are recommended.

5.4 Potential use of the model

At its current form, the model is very user-friendly tool to a**ssess both international impacts of Finnish domestic investments and Finnish impacts caused by international investments or other forms of change.** Consequently, it can be used for "hybrid" evaluations where change is introduced to both Finland and multiple other nations, indicating that **the model can be widely used in both regional and inter-country policy analysis**. It is also as good as if not better tool to conduct basic global value chain analysis as the WIOD base-model as it is basically enhanced version of it with the addition of consumption effects. Additionally, **the tool can be used in ex-post value chain analyses, where the impacts of a project have realised for a specific domain but no information is collected on the wide-spread impacts**.

The model itself can be linked to various combinations of Finnish subnational many-region input-output models with slight adjustments as it is currently linked to a Finnish major region MRIO model as well as Finnish two-region model. Additionally, the model could be linked to another subnational model instead of Finland, though this would require calculating some local coefficients and distributions in addition of needing a working subnational model for set nation. Furthermore, the Finnish model could be linked to another GMRIO following the steps taken in creating the current linked-model, though this would require calculating of multiple values, coefficients and distributions based on that GMRIOTs data.

6. RESULTS & ANALYSIS

The global MRIO model with sub-national Finnish coverage was used to simulate the internationally originating (later referred as downstream) impacts of the European Recovery and Resilience Facility grants on the Finnish economy (appendix D). In conjunction, the Finnish and global sustainability impacts were generated. The simulated scenario is based on information calculated and gathered from external sources (for more detailed description see 4.3) as no set-in-stone plans with broad and exact industry classifications for the grant usage exist to-date. In reality, the tool can be used to simulate the impacts of any investment scenario based on national accounts and global trade data as long as monetary information exists at some classification and detail.

The simulated results are primarily addressed as monetary increase in total output by sector and country as it is the baseline of the model. Extensions to other economic indicators such as value added, GDP and taxes are mainly utilized for the Finnish side of the model, but sustainability extensions are captured for the whole entirety. Additionally, proportioning is used to capture the differences in national performance i.e., indicator per output, and equivalent notions. Therefore, summarized global impacts are presented in addition to Finnish downstream impacts. **For the global impacts, the total of investments are considered. For the Finnish downstream impacts, the impacts from Finnish grant allocations are excluded** t**o clearly capture the downstream impacts of foreign investments if not otherwise specified.** However, the total output impacts on the Finnish economy from these are estimated to be around 3.8 billion euros (own simulation) during the investments phase.

First, in this section the **global impacts are presented as comparisons are drawn from them in the Finnish case**. The overall global impacts by region are visible in figure 20 with Finnish grant allocations and rest of the world impacts excluded. Second, **Finnish downstream impacts are presented thorough three pillars of sustainability.** Third, Finnish performance is evaluated thorough a global value chain design analysis that examines the impact that different value chains have both locally and globally by allocating the funds differentially within and outside of Finland. Finally, a sensitivity analysis on sectoral aggregation is conducted for the purposes of demonstrating the responsiveness of the model to slight adjustments in initial data.

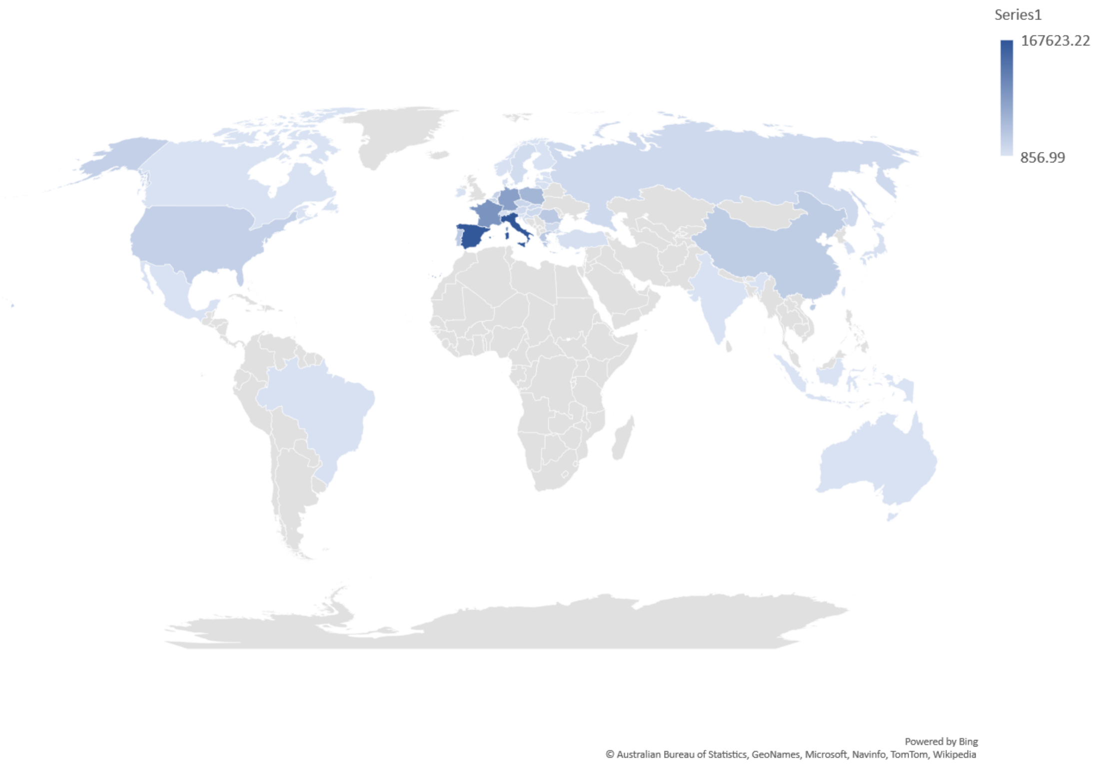

Figure 20. *Increase in global national outputs from the Facility grant allocations*

As figure 20 demonstrates the impacts from the European Recovery and Resilience Facility are not limited to the EU area. The global spread of impacts is the result of global value chains connections. In this case most of the impacts reside within the EU-27 region as most of the investments are allocated to industries closely connected to public administration. The national economic impacts by country are presented later in figure 45.

6.1 Global value chains and sustainability impacts

The European Recovery and Resilience Facility grants of 338.5 billion euros at current prices lead into momentary increase of nearly 1 trillion euros in the total global output. The 295 % larger impact than initial investment is result of multiplicative effect caused by intermediate demand (roughly 50 %) and compensation-consumption loops. This in turn has a vast impact on the global resource use and emissions. The overall global impacts are summarized in table 13.

Table 13. *Global impacts of the Facility grants investments (in million euros)*

Indicator	Unit	Amount	Rise from BAU
Change in output	Millions of euros	998396.23	0.62 %
Carbon-dioxide emissions	Kilotons	220633.6	0.68 %

Gross energy use	Terajoules	5529551	0.71 %
Methane	Tonnes	1502352	0.33 %
Nitrous oxide	Tonnes	62242.7	0.37 %
Nitrogen oxides	Tonnes	64903.56	0.04 %
Sulphur oxides	Tonnes	877899.6	0.40 %
Carbon monoxide	Tonnes	2344451	0.33 %
Non-methane volatile organic compounds	Tonnes	747002.5	0.37 %
Ammonia	Tonnes	196084.6	0.42 %
Land use	1000 hectares	29595.86	0.29 %
Water use	1000 cubic meters	63669340	0.36 %
Biomass	1000 tonnes	115163.7	0.36 %
Fossil fuels	1000 tonnes	496217	0.76 %
Minerals	1000 tonnes	631825.1	0.70 %
Work hours	Hours	1.13E+10	0.56 %
Work years (FTE)	Years	6629800	0.64 %
Employee compensation	Millions of euros	226656.2	0.70 %

The simulated results describe the impacts that the final demand caused by the distributed grants have, treated as investments i.e., money is spent in full for the targeted sectors. Therefore, the investments represent a graduated temporary change in the economy for the investment period (3 years onwards from 2021) and **impacts will retire from the global economy after the time period if they do not create structural changes in the business environment**. The percentual increases in the table 13 refer to these changes caused by the total investments when all grants are spent at once.

Despite all the money being simulated towards the EU-27 regions only 83 % of the impacts take place within that geographical area. In fact, the number two impacted industry in the scenario is the mining and quarrying industry of the rest of the world region which is no surprise as much of the activity happens within the piled world region. As a matter of fact, the democratic republic of Congo is one of the top importers of Finland as a result of large mining and quarrying industry (Finnish Customs, 2019). The overall distribution of output increase by industry is displayed in figure 21 at 56 industry classification.

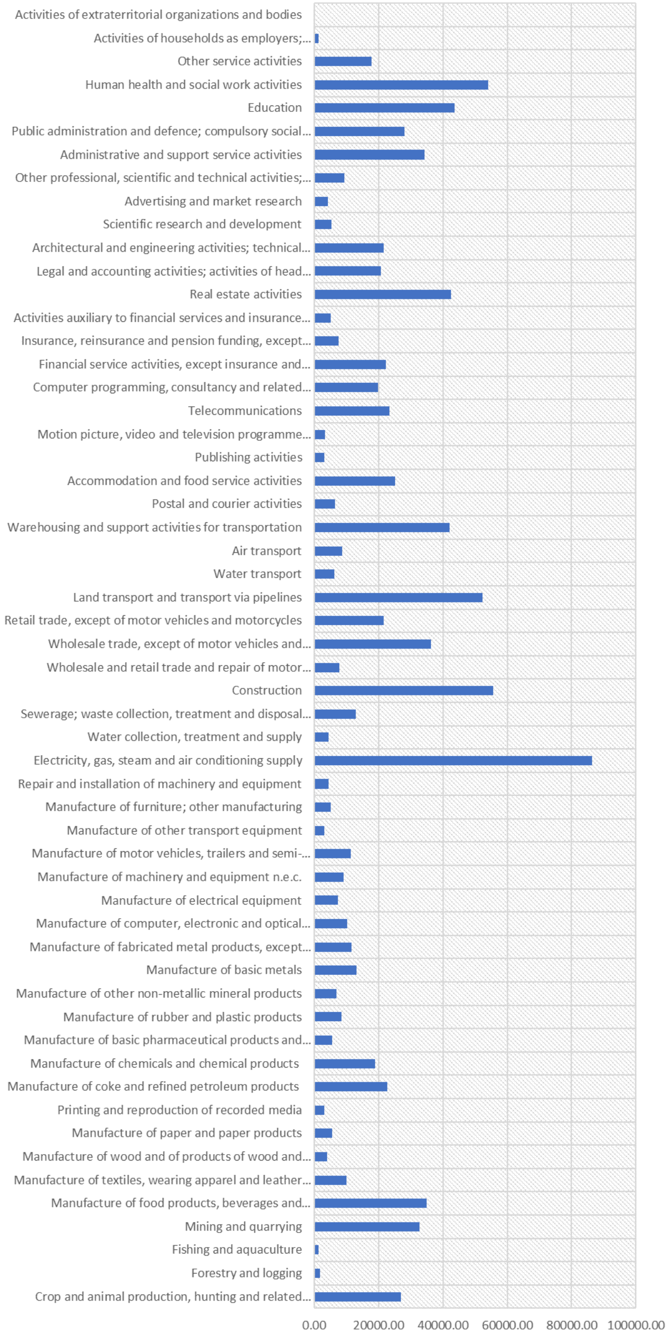

Figure 21. *Impacted sectors worldwide by increase in output (in million euros)*

As much of the national plans allocate money towards green economy it is only natural that the industry *electricity, gas, steam and air conditioning supply* has the most impact in terms of output. Another major beneficiaries are *education, health and public services industries* as a lot of the funds are directly allocated towards these sectors. In reality, more of the money might be allocated directly towards manufacturing industries as they are likely the suppliers of new equipment for most industries (only slightly over 3 % of the grants were directly allocated towards manufacturing industries in the simulation). This is clearly presented in figure 22 with five-activity-grouping of simulated industry allocations and impacts with consumption and direct final demand impacts presented in the chart left and intermediate impacts in the right chart.

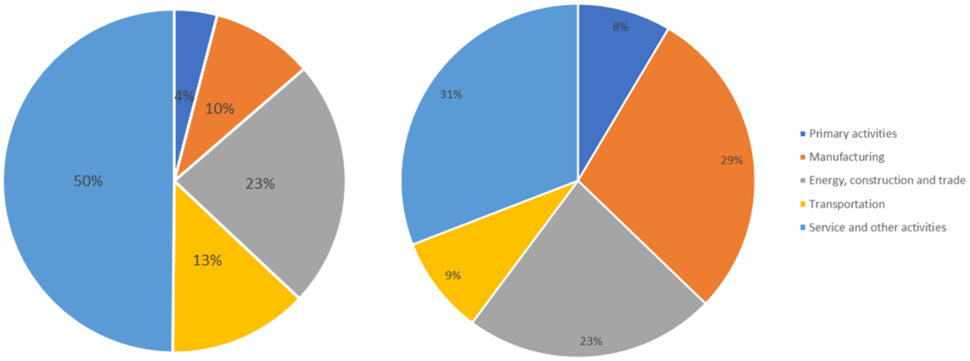

Figure 22. *Impacted industries by large industry groupings*

Some more unforeseen changes are the large impacts on trade (not clearly visible in the figure 22) as no grants were directly allocated towards these sectors in the simulation. However, trade is a central part of business, having large amount of intermediate and consumption effects circulate towards the industry is intelligible in the case. Similarly the high share of manufacturing and primary industry impacts can be explained by intermediate activities and are ultimately a result of the industries pivotal position in global value chains. The total sustainability impacts by country and sector follow the lines of total output changes, and the overall impacts by indicator distribution can be found in appendix E. Although the Facility aims to create greener and more digital Europe, it is clear that a rise in material use and other negatively climate affecting variables takes place during the investment phase, explaining the large increases in the total indicator values.

6.2 Finnish value chains and downstream sustainability impacts from foreign grants use

6.2.1 Economic impacts

The Finnish results are compartmentalized below under the three pillars of sustainability – economic, environmental, and social impacts. Social impacts are covered more-so with socio-economic impacts than social ones as there was no access to distinct and reliable social indicators in this case. However, qualitative conclusions are drawn from the employment changes to further social effects. The environmental impacts are treated as impacts happening within region, ergo production-based approach is applied when looking at total Finnish impacts, but consumption-based approach is applied when directing country-specific impacts to investing regions (or the total of EU-27). For the economic impacts, additional calculations are made to cover the effects to the national economy. Table 14 presents the total downstream economic impacts of the Facility on the Finnish economy with the Finnish grant allocation impacts excluded.

Table 14. *The downstream economic impacts on the Finnish economy (in million euros)*

Unit	Economic indicator	Amount
m. €	**Change in output total**	**1869.1**
	of which due to direct final demand	323.64
	of which due to intermediate demand	1545.5
m. €	**Value added**	**707.48**
m. €	**GDP**	**746.3**
	Rise in GDP	0.3 %
FTE	**Work years**	**7979**
m. €	**Taxes**	**239.1**
	Local income tax	69.1
	VAT	143.9
	Corporation tax	20.7
	Real estate tax	5.3

Table 14 demonstrates that the Finnish economy is impacted heavily by the downstream value flows from the foreign investments. However, in terms of increase in total output alone the Finnish economy clearly is a net-payer of the Facility even if the Finnish grant allocations are considered (2.1 billion euros) as the total net-output-impacts from the Recovery and Resilience Facility fall 14 % short of the 6.6 billion euros that Finland is to pay to European Union during 2028-2058. In terms of value added and total GDP same comparison equates to roughly 40 %. However, these are merely investment phase impacts and Finnish economy is to benefit considerably more from the post-investment phase in reality as the Finnish business environment already has a strong foothold in digital and green technologies.

To put the things in perspective Finnish economy will be impacted 14-times less than the German economy, 29-times less than the Spanish economy and 1.6-times less than the

Swedish economy. On the other hand, in terms of output changes to national GDP Finnish outperforms **two of the other net-payers – Germany and Sweden** – by 0.07 percentage points and 0.54 percentage points respectively in the simulation. However, as the grant allocations significantly differ, more just comparison is the performance of countries in regards of changes in output to the grants received. In this case, the two **outperform Finland** with performance indicators of 3.1 and 2.8 respectively to the Finnish number of 2.7 **but Finland surpasses two of the net beneficiaries – Spain and Bulgaria** – with indicators of 2.4 and 2.0. This indicates that the EU Recovery and Resilience Facility in fact targets "less-performing" countries as it was meant to, but also denotes that the total European impacts could be significantly higher if targeted differentially. However, this is an unfair approach that would have markable impacts on the unity of the EU. One of the contributors to the relatively good Finnish economic performance is the impact distribution across industry groupings which, can be seen in figure 23.

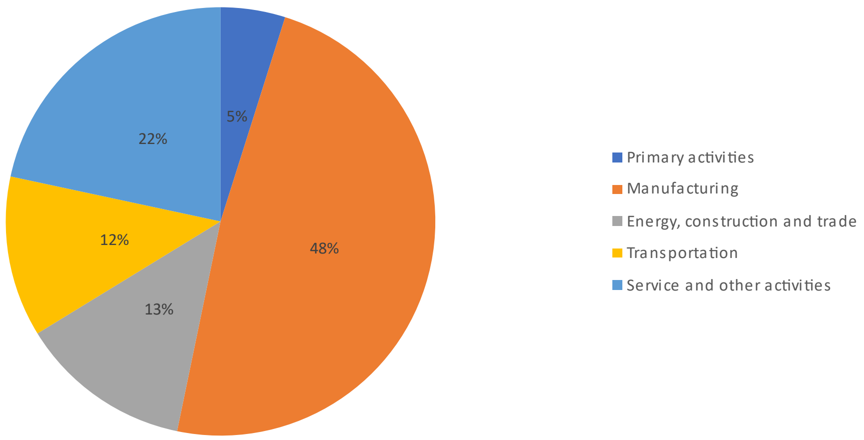

Figure 23. *International impacts of the Facility on the Finnish economy by large industry groupings with Finnish direct grant allocations disregarded*

The Finnish downstream impacts are heavily focused on the manufacturing activities with nearly half of the impacts resonating under the grouping as displayed in the figure 23 above. In comparison to the global distribution of impacts this is considerably higher, indicating that **Finnish value chains are more often than not linked to global value chains with manufacturing connections when compared to global counterparts**. This partially explains the Finnish performance in the scenario – Finland is able to gain 0.36 % increase in yearly output and employment as well as increase of 0.30 % increase in yearly value added from the downstream impacts alone – as more money is typically bound in manufacturing activities (monetary capital in terms of sectoral output in our case), but also indicates that the swarmed environmental impacts be larger within the region. The actual sectoral impacts to the Finnish national economy are displayed in figure 24 below.

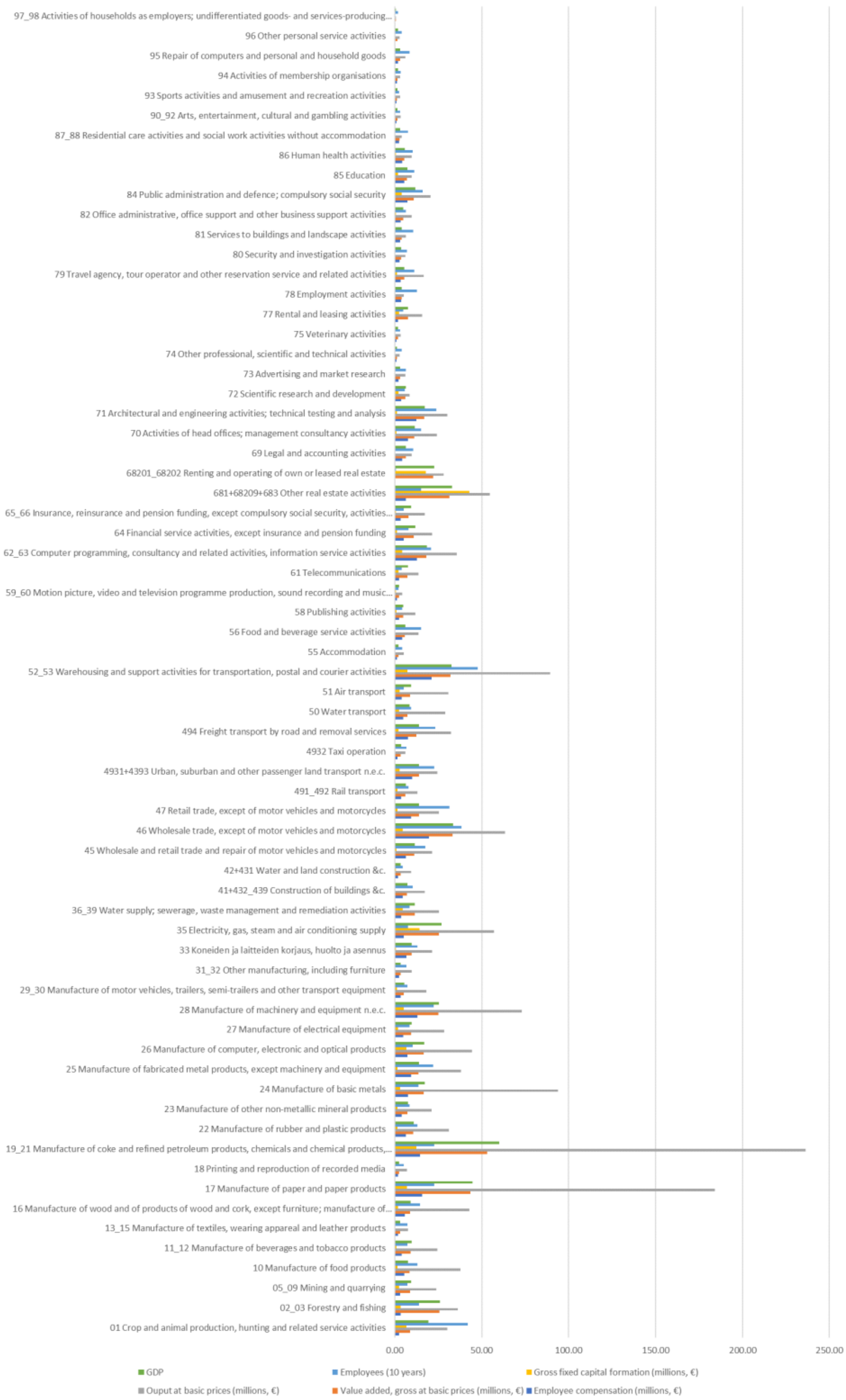

Figure 24. *Downstream impacts of the Facility on the Finnish economy*

Compared to the global sectoral impact distribution (figure 21) the difference is clear. This is sensible as the main affected sectors in Finland are naturally the *manufacture of paper and paper products industry and manufacture of coke and refined petroleum products, chemicals and chemical products, basic pharmaceutical products, and pharmaceutical preparations industries* which are large industries with high number of global and local value chain connections. Much of the Finnish manufacturing impacts are due to the intermediate demand caused by all the sectors in the global value chains. This is clearly demonstrated in figure 25 which captures the orientation of the impacts.

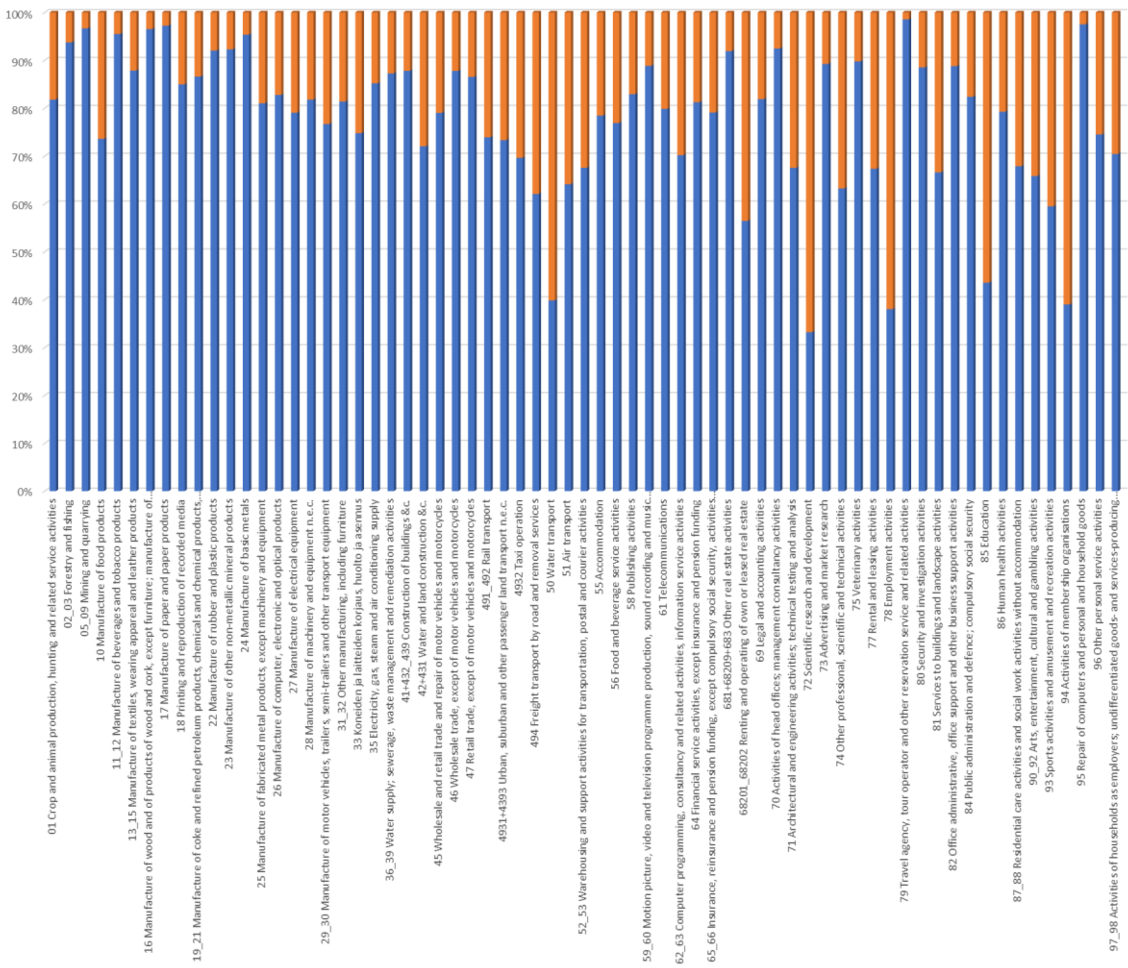

Figure 25. *Finnish downstream impacts by industry and orientation*

The impacts from direct final demand are clearly targeted towards the energy, construction, and service side sectors that the national plans on grant use of the Facility clearly target. Whereas the intermediate demand impacts resonate more heavily towards the manufacturing industry. By comparing the figure 25 to the table 14, the strong position of the manufacturing industry in the five-activity-grouping of figure 23 is clear cut as most of the impacts are due to intermediate demand.

In this simulation impacts due to final demand refer to direct purchases from set Finnish sectors and the multiplicative and consumption effects related. The impacts due to intermediate demand consequently refer to intermediate needs of foreign sectors from the set Finnish industries and the multiplicative and consumption effects related. The strong intermediate effect of **manufacturing industries value chain connections** can be further abbreviated by the mentioned multiplicative effect as typically value chains related to production e.g., *paper and paper products industry* **have manifold of indirect value chain impacts on other sectors**. A large production facility can employ e.g., 200 process workers directly, but the value chain connections grasp to over 1 000 workers directly thorough procuring services of logistic workers, producers and many others whereas the value chains of service activities are typically more tied together. This analogy can be partially observed in the figure 25 as it also covers the **consumption impacts** that **typically resonate more towards service, trade and transportation activities**.

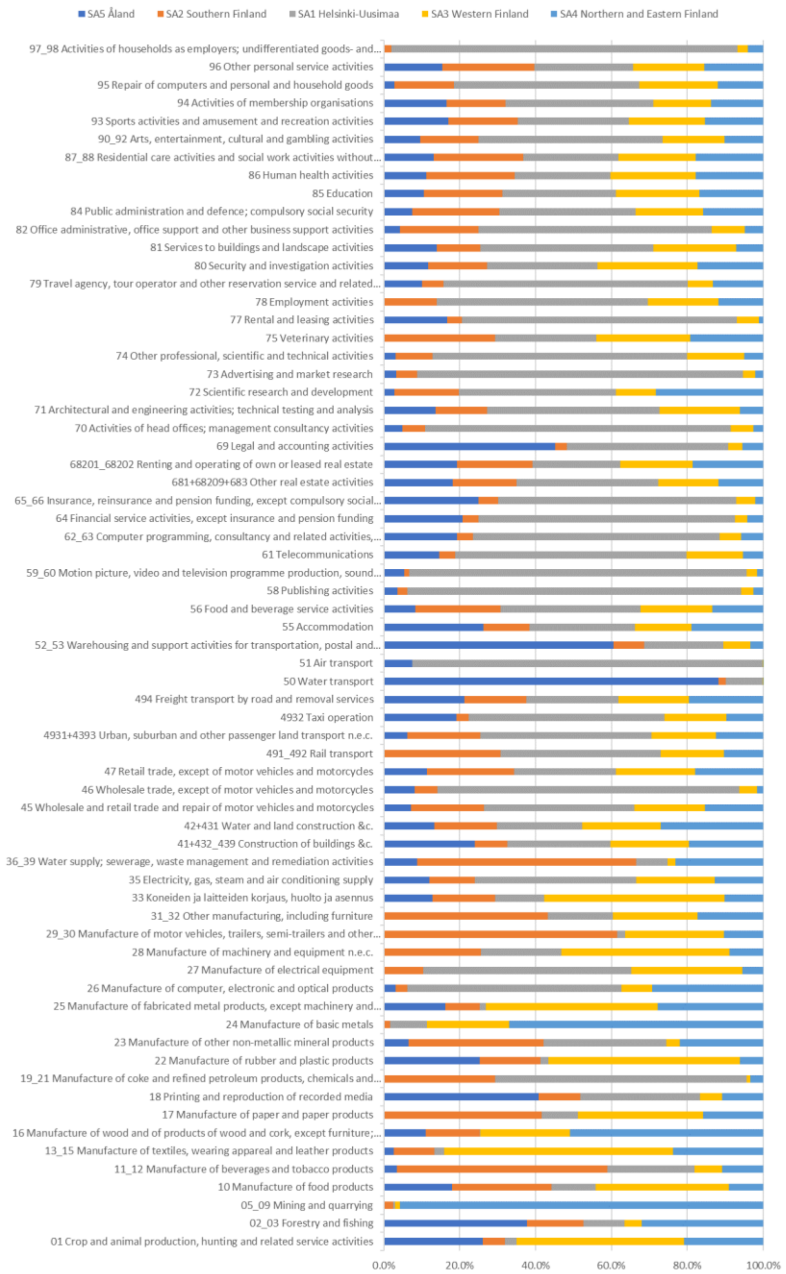

Figure 26. *Finnish per-capita impacts of the Facility by five major regions*

Another interesting viewpoint on impacts is the economic impact distribution between major regions of Finland. The Finnish major region impacts are displayed in the figure 26 above as total regional economic gains per-capita (regional populations based on Statistics Finland, 2021). **Most of the impacts clearly occur in the region of Helsinki-Uusimaa (46 %)**, followed by Western Finland (20 %), Southern Finland (17 %), Northern and Eastern Finland (16 %) and Åland (1 %). That said, the sectoral differences between regions impacts are immense (appendix F). The differences in economic impacts between regions are distinctly large by the total values, but when examined in conjunction with regional populations the separation decreases, though Helsinki-Uusimaa region still stands as a clear-winner of the benefits as it holds high shares in many of the Finnish sectors impacted the most.

In terms of the final 30 % of the grants to be-allocated later and the attractiveness to take part in similar schemes in future the performance of Finland is further analyzed by the shares of total impacts captured by nation. As the investing nations themselves capture most of the benefits, around 40-70 % depending on nation (with Finland capturing 61 % of its own impacts and Estonia 51 %) the shares captured were contrasted on the estimated remaining impacts to be captured by other nations. These are displayed in figure 27 below for the case of Finland.

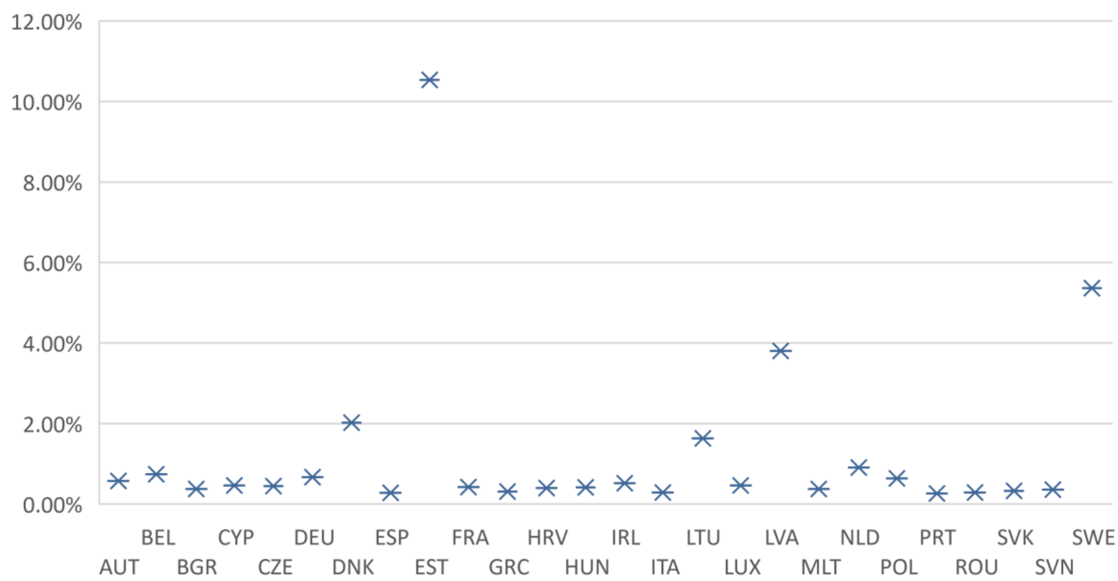

Figure 27. *Finnish performance in capturing the available positive economic impacts by national grants and allocations of a country*

As expected, the Finnish economy is able to capture the impacts of the geographically close-by countries well with Estonia, Sweden and Latvia being the clear stars of the scenario. In terms of the funding distribution of the Facility, the results are lamentable as **Finland is able to capture only a fraction of the impacts originating from the regions of Facility's grand beneficiaries**, namely France, Italy and Spain who gain over 50 % of the distributed grants.

6.2.2 Environmental impacts

The environmental impacts of the Facility were captured with extensions to the economic data. The Finnish downstream impacts total to 495 GWh (1 780 terajoules) of emission relevant energy use (0.1 % of Finnish yearly use), 144 000 hectares of land use (0.4 % of the Finnish land area), 2 130 000 tons of material use (1.1 % of the Finnish DMC) and 67 800 million liters of water use in the simulation (Statistics Finland, 2021). A short clarification on the distribution of environmental impacts for the Finnish downstream results is presented below, ergo the environmental impacts that take place in Finland (production-based impacts) but are allocated to the countries of final demand's origin if consumption-based responsibility approach is applied.

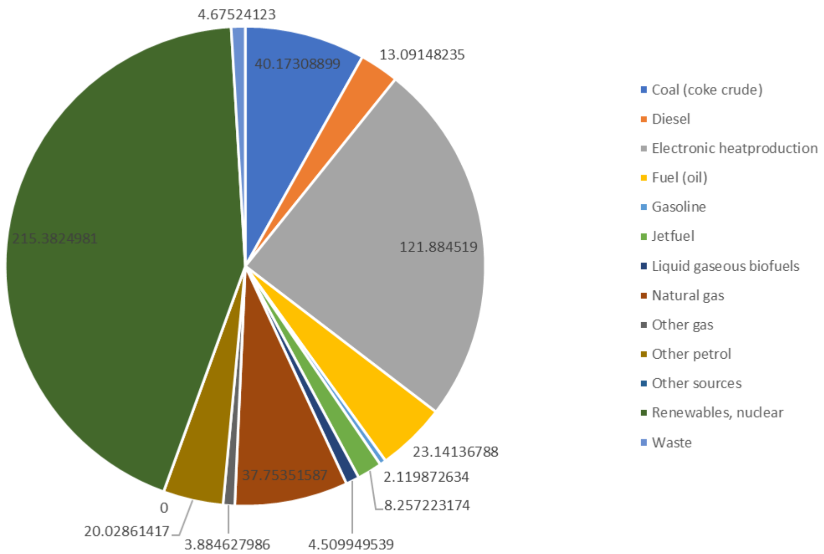

Figure 28. *Distribution of emission relevant energy use by source in GWh*

Figure 28 presents the distribution of total sectoral emission relevant energy use by source in terajoules. It is minor to gross energy use as it only consists of energy that causes emissions directly by excluding the non-energy use of energy commodities and input of energy commodities for transformation into fuels from the gross energy use accounts (Corsatea et al., 2019) The main source of the energy use is nuclear energy and renewable energy sources (44 %), with electronic heat production taking up another large share of the total (25 %). However, the results and figure related are slightly outdated as there are reforms such as the run-down use of coal in energy production within next 10 years in Finland which in reality makes the total shares of energy use by fossil fuels lesser during the investment phase. The top contributors in terms of energy use are the *manufacture of paper and paper products industry, manufacture of coke and refined petroleum products industry and electricity, gas, steam and air conditioning supply industry*.

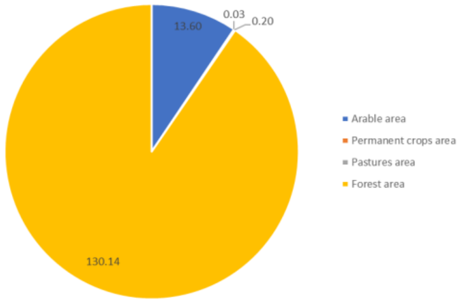

Figure 29. *Distribution of land use by area type in 1 000 hectares*

Figure 29 presents the distribution of total land use by area type in units' of 1000 hectares. The used land is almost entirely made up of forest area (90 %), but 10 % of arable area is also used. Primary activities *crop and animal production, hunting and related service activities and the forestry and logging industries* practically contribute the whole use in this case. Assessment of different land use impacts is important in the ex-ante evaluation of the Facility especially in terms of land type as different types of land use utilize both different types of land and in different time spans (Genty, 2012). Therefore, **the availability of land becomes relevant when allocating investments by location sub-nationally.**

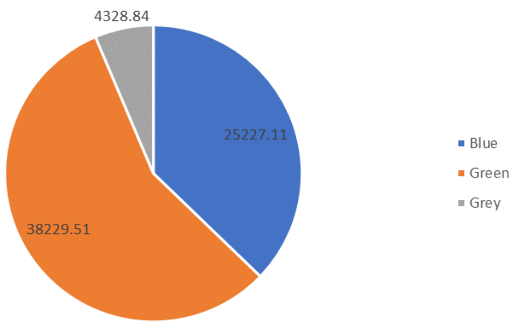

Figure 30. *Distribution of water use by type in cubic meters*

Figure 30 presents the distribution of total virtual water (water embodied in production) use by water type in the units' of 1000 cubic meters. Green water (water stored in soil from rain transpired by crops) covers most of the water use with 56 % of total use, followed closely by blue water (water in surface and groundwater reservoirs) with 37 % of total use and the grey water (water that becomes polluted during production) covers the rest of water use in this case (Clothier et al., 2010). Much like the availability of land use, the availability of water resources should be estimated when allocating the investments to different regions to optimize the environmental impacts and costs. The top contributors to the water use mix are the *forestry and logging and crop and animal production, hunting* *and related service activities industries* due to the high use of green water and the *electricity, gas, steam and air conditioning supply industry* that uses high amounts of blue water.

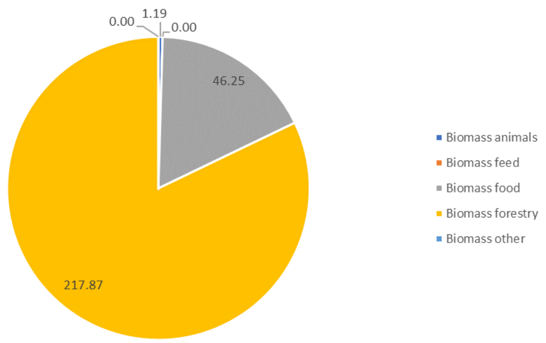

Figure 31. *Distribution of biomass use by type in 1 000 tons*

Figure 31 presents the distribution of biomass use by type of used and unused biomass combined in the units' of 1000 tons. Biomass constitutes 12 % of the total materials use in the case with most of the use being forestry material (82 %) and nearly all the rest food (17 %). The biomass use is nearly evenly split by the *forestry and logging and crop and animal production, hunting and related service activities industries* in the case as extension data was only available for sectors 1-4 in the 56-sector classification.

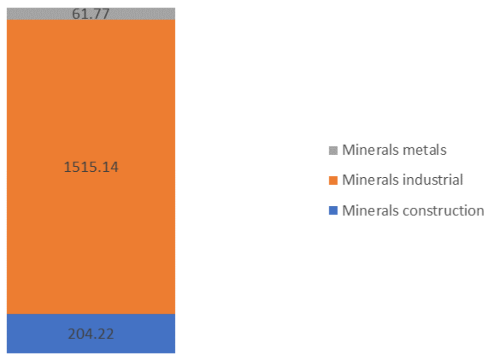

Figure 32. *Distribution of mineral use by type in 1 000 tons*

Figure 32 presents the distribution of total mineral use by type in units' of 1000 tons. Consisting of 85 % from industrial mineral use, 11 % from construction use and 4 % from metals use, the mineral use covers 84 % of all the materials use, with *mining and quarrying industry* constituting all of the mineral production. Much like minerals, *mining and quarrying industry* also covers all of the fossil use, consisting of 82 750 tons of fossil coal and contributing 4 % to the total materials use.

The material indicators in figure 30 (biomass) and 31 (minerals) combine both the used and unused materials though separate indicators could be drawn. However, as used materials represent the extracted materials entering economic system for direct consumption or further processing and unused materials represent the extraction that is done but do not enter the economic system such as by-catch and parting materials (Genty, 2012) the indicators are grouped – the environmental impacts occur whether the materials enter the economy or not. **Considering the material use is important early on in the planning phase of projects as all of the materials may not be readily or locally available. Hence, a good estimate on the material needs helps to optimize the sustainability impacts of investment allocations**.

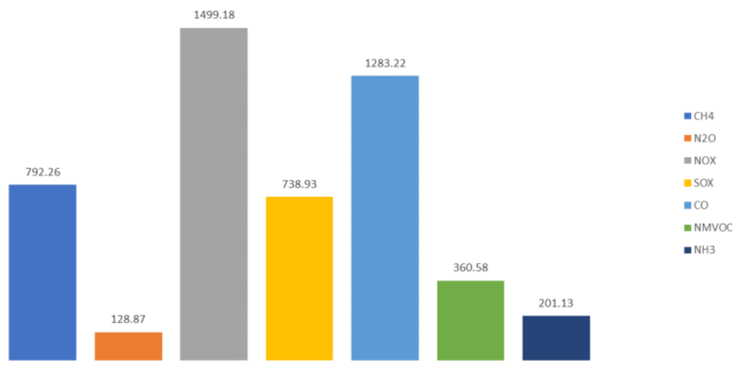

Figure 33. *Distribution of emission impacts by type in tons*

Figure 33 presents the distribution of emissions generated by the type in units' of tons. The chart displays that the majority of the created emissions consists of nitrogen oxides and carbon monoxide. **In addition to these emissions 289 kilotons of carbon dioxide is emitted** making it the "top emission" in amounts of tons. However, if global warming potential (GWP) or other emission measurement system was applied to capture the true environmental impact of the emissions, the indications would be very different. For emissions, the emitting sectors vary clearly by type, hence the top three emitting sectors (in 56-industry classification) for each of the emission type are presented in table 15 below.

Table 15. *The Finnish top three emitting industries by emission type*

Emission indicator	**Top three emitting industries**
Carbon dioxide	Electricity, gas, steam and air conditioning supply (24), manufacture of coke and refined petroleum products (10) and manufacture of paper and paper products (8)
Methane	Forestry and logging (2), crop and animal production, hunting and related service activities (1) and other service activities (54)
Nitrous oxide	Forestry and logging (2), crop and animal production, hunting and related service activities (1) and manufacture of chemicals and chemical products (11)

Nitrogen oxides	Water transport (32), electricity, gas, steam and air conditioning supply (24) and manufacture of coke and refined petroleum products (10)
Sulphur oxides	Water transport (32), electricity, gas, steam and air conditioning supply (24) and manufacture of coke and refined petroleum products (10)
Carbon monoxide	Manufacture of coke and refined petroleum products (10), air transport (33) and manufacture of paper and paper products (8)
Non-methane volatile organic compounds	Manufacture of paper and paper products (8), electricity, gas, steam and air conditioning supply (24) and manufacture of chemicals and chemical products (11)
Ammonia	Forestry and logging (2), crop and animal production, hunting and related service activities (1) and fishing and aquaculture (3)

Absolute values give good implications of the total impacts related to the upcoming investments. These provide policymakers, governments, and companies the information required to estimate the needs and requirements of the future demand (e.g., required land, materials etc.) and adapt accordingly whether it is to reserve areas, upscale production or react to the possible changes in commodity prices. What the absolute values do not tell are the performance of individual sectors and nations in relation to environmental impact. These are important factors to consider as the allocation of funds can have significantly varying impacts depending on the location. Table 16 hints at Finnish sectoral performance by capturing the environmental impacts of Finnish downstream impacts by the unit of grouping specific output (million euros).

Table 16. *Finnish environmental impacts and performance by large industry groupings*

Large industry grouping	CO_2 (kt /m. €)	ENERGY (GWh/m. €)	LAND (1000 ha/m. €)	MATERIALS (1000 t/m. €)	WATER (1000 m^3/m. €)
Primary activities	0.142826	0.060573	1.593196	23.55869	439.2619
Manufacturing	0.125326	0.309370	NA	NA	4.45200751
Energy, construction and trade	0.386836	0.648455	NA	NA	99.2825775
Transportation	0.310915	0.142258	NA	NA	NA
Service and other activities	0.009136	0.057959	NA	NA	0.32511892

The table 16 depicts that primary activities are the grand contributor to land, material, and water-use. Additionally, the activities hold relatively high shares of carbon-dioxide emissions and energy use, the small impact directed to these industries constitutes that they emit only 4.5 % and 1.1 % of the total impacts respectively with this grouping. In total, manufacturing industries can be seen as the net-emitter of emissions and the top-environmental consumer in the scenario which is only natural as they cover nearly 50 % of Finnish economic impacts (figure 23). Following this, it is evident to make out why *manufacture of paper and paper products, and manufacture of coke and refined petroleum products as well as manufacture of chemicals and chemical products, basic pharmaceutical products and pharmaceutical preparations and electricity, gas, steam and air conditioning supply* are the top emitting industries, while the service industries are close to the bottom of nearly all comparisons of the environmental impacts, both by the total amounts and in relation to output.

The Finnish total environmental results are moderate in general and in comparison to other countries total results. This is highlighted by figure 34 that compares six EU-27 countries carbon-dioxide impacts from different national grant allocation investments. In the comparison Finland is only clearly outperformed by two very developed countries, Sweden and Germany, whose intermediate impacts favor service sectors more.

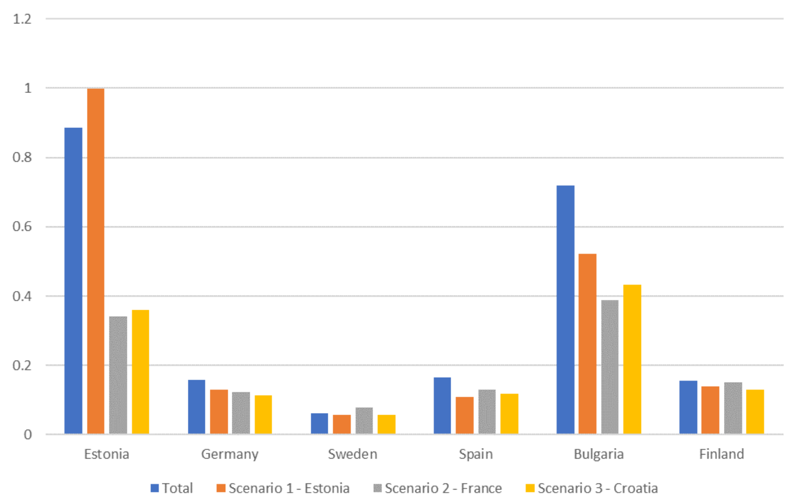

Figure 34. *The carbon-dioxide "performance" of six EU-27 countries*

Figure 34 displays that the environmental impacts are very dependent of the case. It also indicates on the different environmental performances of countries when the results are looked in different schemes. For instance, the Estonian total carbon-dioxide performance on its own gives false image of the country's performance as Estonia in fact allocates its own grants heavily to energy-industry reforms. Looking at Estonia's impacts from other countries investments, it is clear that carbon-dioxide emissions related to these indirect impacts are moderate in the region and the total carbon-dioxide impacts are only high because of Estonia's own investments. Similar effect can be seen for most of the countries investing in energy-industry. This brings up one of the challenges of the analysis – the simulation considers the historical industry averages more so than the actual technological progress gained – resulting in high carbon-dioxide (and other) emission amount when in fact the reforms and investments result in reduction of yearly emissions in the post-investment era with the implementation of more effective and renewable solutions.

As the Finnish grant allocations are excluded from the main scenario, the Finnish performance can be analyzed more profoundly than other nations. This is done in figure 35, where the Finnish "performance" is further evaluated by comparing the share of total available carbon dioxide and economic impacts captured from national investments. The figure displays that for the most part, total economic gain is outperforming the carbon-dioxide emissions despite Finland capturing much of the intermediate impacts thorough manufacturing industries global value chain links. This is much due to the environmental efficiency in Finnish manufacturing and a lot of funds being tied to production but also to the specific global value chain links i.e., the Finnish Estonian originating carbon impacts are minor in comparison to Estonian ones despite the countries energy sectors active co-operation. In fact, much of the economic impacts from Estonia in the scenario circulate to the primary activities and service sectors of Finland in addition to manufacturing industries with only a fraction of the impacts circulating to the Finnish energy sector.

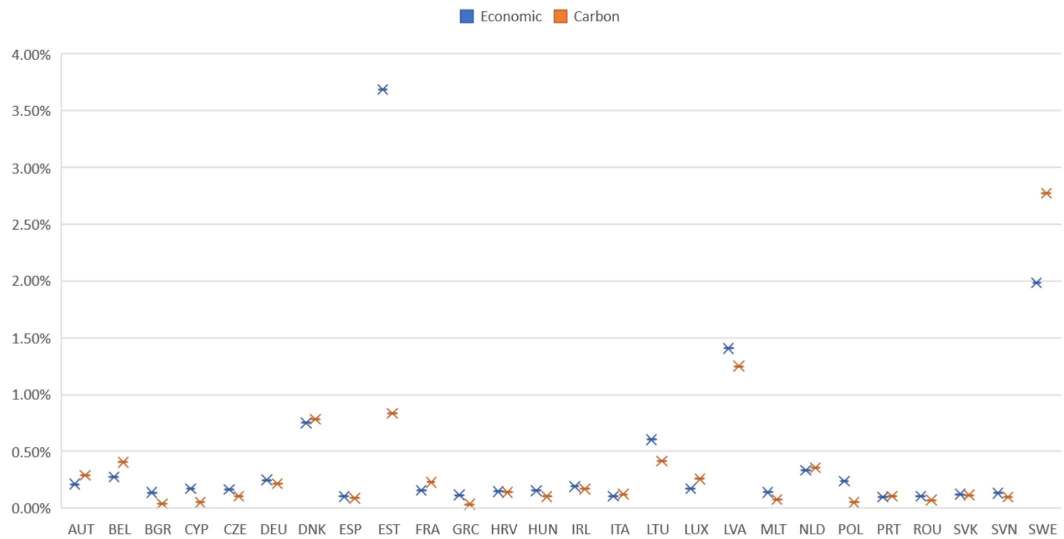

Figure 35. *Finnish capturing of foreign economic impacts and carbon emissions*

6.2.3 Social impacts

Much like the environmental impacts of the Facility, the social impacts were captured with coefficient extensions to the economic data. **In total the Facility will generate 8**

000 FTEs (full-time equivalent) to the Finnish economy when Finnish direct grant allocations are excluded. *For the Finnish FTEs a more accurate appraisal of employment creation was used (in comparison to other countries FTE changes) derived from the Finnish sub-module of the MRIO model. Therefore, a slight deviation occurs between the total work hours and FTEs in the Finnish case as the work hours are taken from the WIOD side of the model and FTEs are counterbalanced with Finnish side of the model. This deviation is a result of varying satellite accounts between the Finnish side and WIOD side of the model as the Finnish coefficients on sectoral employment creation per unit of output are notably higher for the majority of the classified industries compared to the WIOD satellite accounts. The variation is tangible as Finnish side of the model is based on more recent economic data, the detailed industry aggregations slightly varies between the model sides and as some harmonization is used in the statistics combination.* The division of Finnish FTEs by five-activity-grouping is displayed in figure 36 below.

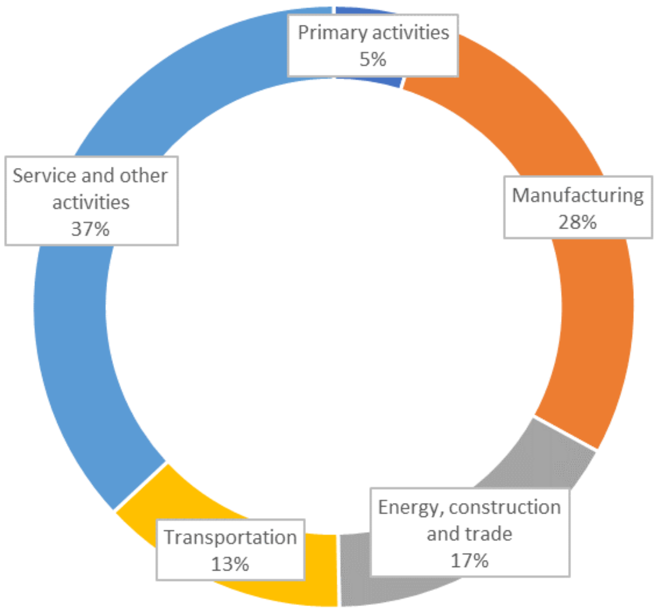

Figure 36. *Finnish employment created by large industry groupings*

The employment impacts by grouping clearly differ from the total output by grouping as nearly half of the increase in output occurs in manufacturing sectors (figure 23). **In terms of FTEs, the service (and other activities) industry clearly outweighs the manufacturing impacts** in the case of Finland but balance out slightly in terms of absolute values of employee compensation. The comparison of total socio-economic impacts by five-activity-grouping is displayed in figure 37.

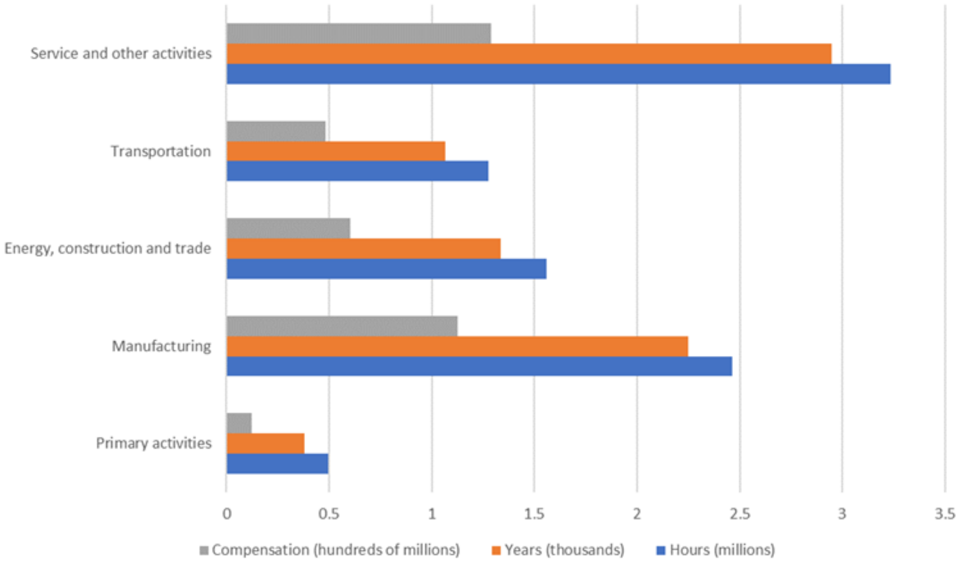

Figure 37. *The Finnish socio-economic impacts by large industry groupings*

From the over 9 million Finnish work hours created, 360 million euros of labor compensation is circulated to the workforce. Most of the distributed compensation finds its way to the high-skilled workers as displayed in figure 38 below.

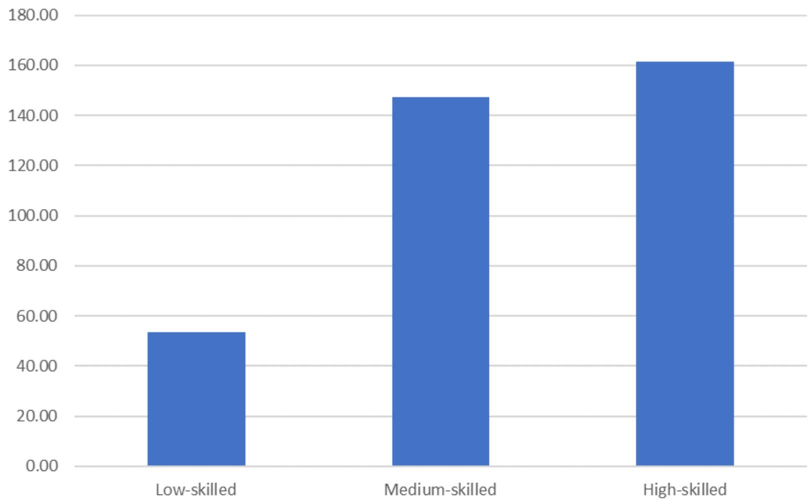

Figure 38. *Total compensation distributed to workforce by skill group*

The distribution is no surprise, considering that much of the allocated grants are aimed enhancing digital and green economy and as the Finnish workforce is considered to be highly educated in general. The compensation spread also explains the rather moderate number of FTEs generated as the labor compensation builds up to over 45 000 € a year per employee on average. Despite most of the money resonating towards high-skilled workers the actual workhours and employment created divide more evenly as displayed in figure 39 below.

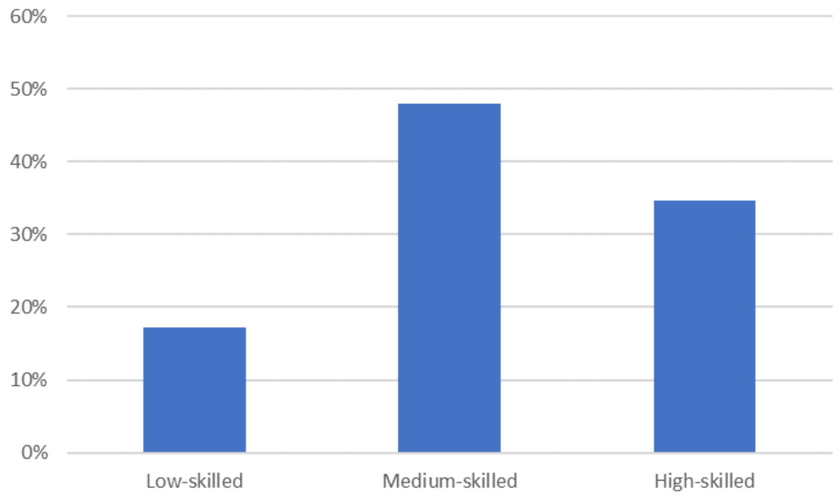

Figure 39. *Shares of total employment created by skill group*

This means that **more medium-skilled than high-skilled employment is created despite high-skilled workforce having the largest share of the total compensation**. For the Finnish government all of this means more taxes, more economic stimulation, and less unemployment to compensate the dent caused by the payments to EU later. Indications to decrease in crime, poverty and other social sustainability indicators can also be straightforwardly drawn though the relatively low-share of low-skilled employment created can lead into inequalities. However, as Finland constantly pushes the average education level higher this can be seen as the right direction in the long-term, also supported by the fact that many of the other EU-27 nations grant allocations are targeted towards enhanced education.

Relative to other nations, one unit of Finnish output creates 4.3 years of employment, where the total global average is 6.7 years of employment per unit of output, marking a difference of 36 %. This can be explained by both the differences in the wage-gaps between countries and the differences in required skill-levels for work as seen in figure 39 and appendix E. However, compared to nations with similar characteristics the Finnish indicator is fair as corresponding indicator for Sweden is 4.1 and 5.5 for Germany. Though if creating employment would be seen as the absolute goal, allocating more of the funds to countries such as Estonia and Bulgaria would be the solution with corresponding values being 13.2 for Estonia and 25.1 for Bulgaria. The high numbers of the two countries also highlights both the importance of the Facility's efforts in balancing the socio-economic differences within EU and the high global average in employment per unit of output in this scenario. The same story continues if the employment is examined per unit of invested million euros by country (grants allocated for use).

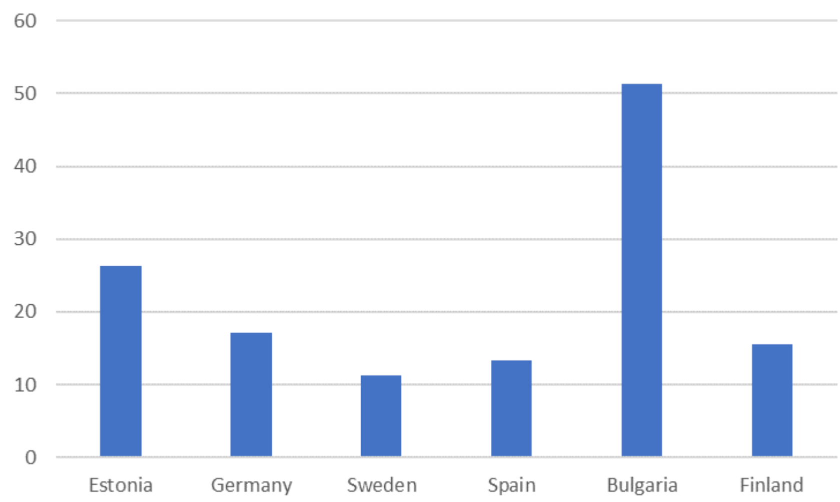

Figure 40. *Differences in emp FTEs created per one million euros of grants*

As seen in the figure 40 the less developed countries still hold the top spot in terms of employment even when the unit is changed from per output to per one million invested. *In the figure 40 the Finnish investment are included for fair comparison.* Though it would seem that the investments would be best allocated to countries like Estonia and Bulgaria in terms of socio-economic impact, it has to be kept in mind that these investments would cause more environmentally negative impacts in total as seen in figure 34 in terms of carbon dioxide. Therefore, in terms of total European sustainability impacts the differences are rather minor and highly dependent on viewpoint.

6.3 Influence of global value chain design on final impacts

6.3.1 Impact of foreign investments geographic location

The impact that global value chain design on the final results was studied by analysing the impacts of sectoral aggregation and alternative sectoral distribution of funds as well as alternative subnational and global allocation of funds. In this case global value chain design covers the impact of sector-specific structures to individual impacts, the nation-specific structures to individual impacts and most of all the impacts of nation-sector-specific impacts to the end results. For example, Finland can have a considerably larger chunk of the overall impact of Estonian trade in comparison to Swedish trade, but the impact of specific sector (e.g., *manufacture of paper and paper products industry*) in Sweden can be of far greater importance than the same sector in Estonia.

Four different examinations are made to address global value chains in the Finnish case. First, the Finnish shares of impacts are studied between nations that have similar national plans in terms of sectoral allocation of funds. Second, the impact of grant allocation itself is studied by allocating the grants of EU-27 nations besides Finland in different manner. Third, the analysis of base results in comparison to established listing of the most attractive partners (in terms of foreign investments home impact) of Finland already outlined in chapter 5.2. is extended. Lastly, the impact of Finnish originating value chains is studied by taking a look at global and home impact-circulation effect when the Finnish grants are brought into the Finnish economy as investments in different sub-regions of the country.

Table 17. *Results by unit of indicator per grants allocated to a nation*

Indicator	BGR	FRA	IRL	PRT	ROU
Finnish impact					
Output (millions, €)	0.0046	0.0047	0.0053	0.0031	0.0032
Carbon-dioxide (kt)	0.0007	0.0007	0.0007	0.0005	0.0005
Work years (10 years)	0.0019	0.0020	0.0024	0.0013	0.0013
Global total					
Output (millions, €)	3.3232	2.9944	2.8014	3.1478	3.0375
Carbon-dioxide (kt)	1.7050	0.3137	0.4271	0.4345	0.6808
Work years (10 years)	5.4707	1.4161	1.2697	2.5071	4.1622

Table 17 presents the examination one. It captures the total impacts created per million of grants allocated to the Finnish and the global economy, between five geographically distant countries (from Finland). As the table depicts Finland is best able to capture the Irish and French impact despite the nation's overall impact per grant allocated figures being relatively low. **The determining factors for the case are the slightly closer location of the countries in comparison, the lower inputs to local and nearby-region favouring sectors (such as transportation) and the overall structure of specific global value chains**, for example France is a close trading partner of Germany who has notably more connections to Finland. This is all expected, and the interesting factor of the example is in fact the position of Ireland in the simulation as it was previously found that the Irish service sectors can have negative impact in Finnish operation (table 12). In the baseline case, the Irish impact on Finnish output is 0.19 % of global total and 0.53 % by grants allocated, positive and notably higher than e.g., France's 0.16 % and 0.47 %, Romania's 0.11 % and 0.32 % or Czechia's 0.17 % and 0.52 % in spite of the fact that much of the investments are allocated under the groping of service and other activities.

6.3.2 Impact of differing national grant allocation grounds

Examination two was carried out by introducing three alternative grant allocation (between countries) schemes to the model whilst keeping Finnish investments excluded from the scenario and the Finnish share of the grants at original 0.60 % of the total. The three introduced scenarios were 1. distributing the available 336.4 billion euros evenly between the EU-27 (minus Finland) countries, 2. distributing the grants based on share of the EU-27 population of 2020 and 3. distributing the money based on nominal GDP by allocating most of the money to the lowest performing countries (individual shares of nations were between 6.1 % and 2.1 %) to balance out socioeconomic differences within EU. The results of the scenarios are presented for both the extended Finnish downstream and summarized total global impacts in appendix G.

The key-takeaways from the analysis is that while the total global impacts from the changes are close to none (-0.3 % to 2.6 %) the impacts on the Finnish economy are huge (up to 150 % increase economically in less realistic scenarios). This begs the question about the distribution of grant allocations of similar schemes in future, especially as even in the most realistic scenario of the three alternatives (population-based distribution) the Finnish economic and socio- change is +29 % with environmental change being around +20 % much thanks to high grant shares of Finland's important global value chain connection countries such as Germany, Poland and the Netherlands.

6.3.3 Impact of nation specific investments and value chains

Continuing with the idea of top GVC partners, the top trading partners of Finland were further analysed by both the ability of Finland to capture shares of nations total impacts and impacts per allocated grants by nation. These were reflected back on earlier analysis of Finnish top trading partners which displayed that only the top-three trading partners were the same between the Facility and original tests, resulting in table 18 below.

Table 18. *Comparison of the original Finnish top trading partners and the Facility partners*

Original	Facility
EST	Estonia
SWE	Sweden
LVA	Latvia
LTU	Denmark
SVK	Lithuania
DNK	Netherlands
NLD	Belgium
DEU	Germany
BEL	Poland
POL	Austria

FRA	Ireland
AUT	Czechia
HUN	Luxembourg
BGR	Cyprus
CZE	Malta
CYP	France
ITA	Bulgaria
MLT	Croatia
HRV	Hungary
LUX	Slovenia
ROU	Slovakia
ESP	Romania
GRC	Italy
PRT	Portugal
SVN	Spain
IRL	Greece

The clear difference between columns in table 18 is result of difference in investment allocations between the original trading partner runs and the Facility runs as the investments in original ones were evenly distributed between sectors of a country and the Facility heavily favours more energy and service-oriented investments. However, the most important result, external from the table, is the fact that **only investments by three countries (Denmark, Ireland and Slovenia) with the Facility investment allocation were able to contribute more positive impacts to the Finnish economy in terms of economic benefits per money invested than the original runs**.

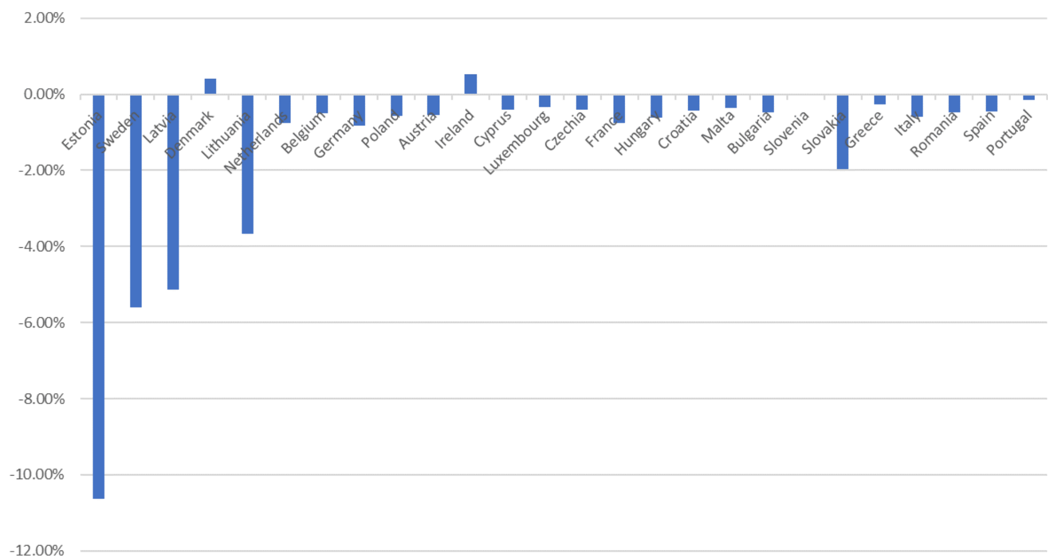

Figure 41. *Difference in total Finnish economic impact between the original trading partner runs and basic Facility scenario run*

Figure 41 above presents the by country changes per total investments. These results are further undermined by the fact that the shares of capturing the impacts from top-trading partners are significantly reduced (up to -10%) as a result of rather minor investments to manufacturing industries. However, the moderate reduction in German, French, Italian and Spanish values is positive factor when considering the total changes.

6.3.4 Impact of subnational value chains

To study the impact that sub-national value chains can have on final results three scenarios with differing regional investment allocations of the Finnish received grants were ran. First the baseline Finnish scenario was ran on the sub-national MRIO side of the model with regional funding allocated based on regional outputs by sector. For the second run, the first allocation was balanced with regional population. Third, the allocation was comprised with idea of "enhancing regional equality", meaning that much of the funds from Helsinki-Uusimaa region were directed to other Finnish regions, especially to the Northern and Eastern Finland. Table 19 presents the main percentual differences between different indicators of second and third run to the first run (base scenario).

Table 19. *Impact differences from altered Finnish regional funding allocation*

Indicator	Second run	Third run
Finnish		
Output	0.64 %	1.52%
Value added	0.74 %	1.85 %
Energy use	0.31 %	1.35 %
Land use	7.03 %	17.89 %
Water use	2.85 %	7.33 %
Material use	6.73 %	17.76%
Carbon-dioxide	-0.31 %	0.12%
Total work years	1.50 %	3.81%
Imports	**-1.78 %**	**-4.34%**
Global		
Output	0.02 %	0.01 %
Carbon-dioxide	-0.76 %	-1.28 %
Work years	0.13 %	0.34 %

Allocating the Finnish investments a different manner subnationally has a clear impact on national indicators as seen in table 19. In scenario 2 where the total changes to baseline scenario 1 are rather minor, **the differences in values can be explained with decreased need of imports i.e., more local production is used to meet the final demand. The changes between the first and the third scenario are notable as the economic impacts rise by up to 2 %** and the land, water and material use increases vastly. This can be explained by the allocation of funds to more rural areas where the value chains differ notably (see appendix H). The evident reason for rise in environmental indicators is the fact that more money circulates to manufacturing industries and primary activities whilst the total economic impacts circulating to service sectors decrease. Therefore, **allocation of funding between regions should be done based on desired sustainability impacts as second and third allocation scenarios clearly boost economic and social impacts while the environmental impact as a total hinders**.

When looking at regional funding, the circulation of impacts should also be considered as much of the money allocated circulates to different regions within the nation in spite of funding (final demand) being allocated to set regions. Regions themselves clearly capture the largest chunk of the impact, evidently due to the direct funding of the region but can “fail” in capturing the total impacts related to local projects. In original allocation scheme (run 1) Southern Finland clearly captures the most impacts (7 % more than the runner up, Helsinki-Uusimaa) in terms of total economic impacts per grants allocated to the region. However, when the allocation scheme is changed so are the value chains and ultimately the total impacts. In this case, this appears as ample leap in the value of the same indicator for Helsinki-Uusimaa region detriment to other regions as the region is able to capture much of the intermediate impacts. In the grand scheme of things, Helsinki-Uusimaa is clearly affected by high decrease in grant allocations in scenario runs 2 and 3 as displayed in figure 42. However, as said by capturing high share of the Finnish intermediate impacts the changes to Helsinki-Uusimaa are still rather minor in terms of change in output. Therefore, for the purposes of “enhancing the regional equality” in this case, a greater allocation of funding to regions besides Helsinki-Uusimaa seems very acceptable as the region will benefit largely in any case due to indirect impacts and the total national impacts are higher in these scenarios.

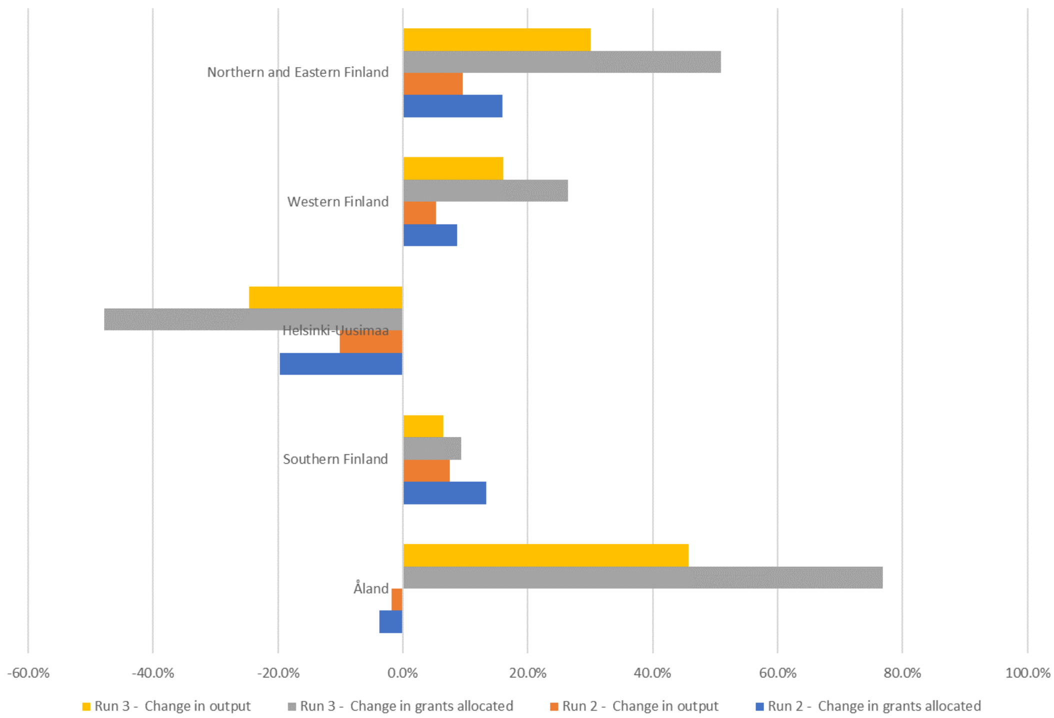

Figure 42. *Changes in total output and grants allocated to the major regions*

The total global impacts remain largely same by count of every sustainability indicator in the scenarios in total as expected, but the results present an important detail in form of the Finnish import needs decreasing for the runs 2 and 3 in comparison to the initial run. **In other words, this denotes that by allocating the funds differently between Finnish major regions, Finland is able to capture more of the total global impacts itself in detriment to other regions of the world as the global changes are less than a million euros and Finnish changes tens of millions of euros.**

6.4 Influence of differing sectoral aggregation in modelling and model statistics on interregional sustainability impacts

The impact of sectoral aggregation to final results was analysed with sensitivity analysis on the distribution of national investments. This was done by creating two realistic alternative sectoral investment allocation scenarios based on existing output structures of economies and the overall green and digital agenda of the Facility. In practise, the baseline scenario was altered 1. by distributing 50 % of national grant spending based on existing output structure in the WIOD-module and 50 % based on the original baseline scenario and 2. by allocating 30 % of the energy, health, and education spending to manufacturing industries whilst keeping the rest (70%) in line with original scenario. Figure 43 displays the three alternative scenarios in terms of output, carbon-dioxide emissions and employment created.

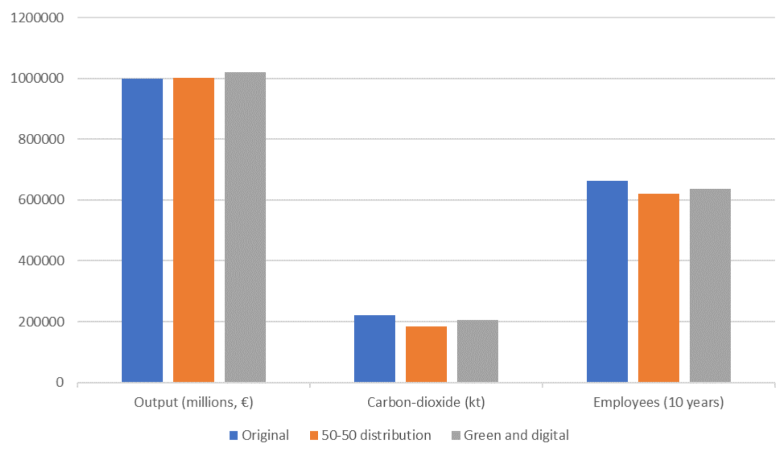

Figure 43. *Main global indicators for alternative sectoral grants distribution scenarios*

As displayed in the figure total changes caused by sectoral aggregation in the case are rather minor in total. In terms of output the change from baseline scenario is 0.26 % in the case of 50-50 distribution and 2.26 % in the digital and green purchases emphasizing scenario. Larger variation can be seen in terms of both carbon-dioxide emission and employment created as both of the scenarios create less emissions (-16.0 % and -6.5 %) and employment (-6.5 % and -4.1 %). However, the variation is significantly larger when individual sectors or countries are examined. In terms of sectors extensive variation is evident as the allocation multiplies for many industries. In terms of individual countries, the variation is notable as the Estonian, Bulgarian and Spanish indicator values present highly negative changes on all levels (around 4 % negative change in terms for output) in both scenarios whereas the Swedish and German economies see a positive boost of 7.5 and 11.1 % in output, and 1.4 and 4.2 % in employment created whilst keeping the changes carbon-dioxide emissions at moderate levels.

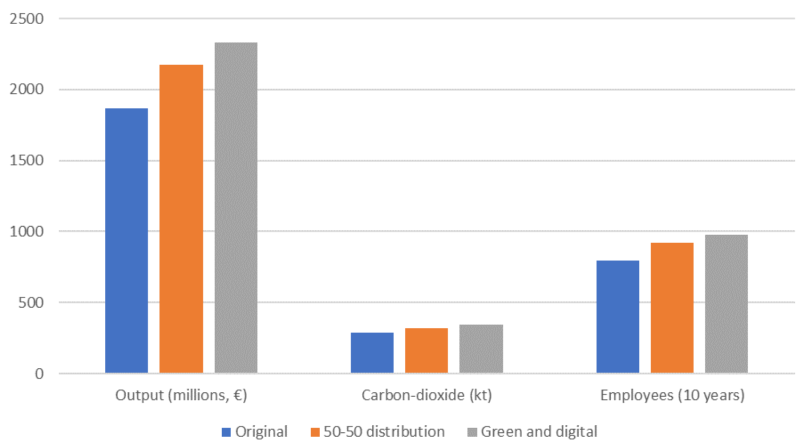

Figure 44. *Alternative distribution impacts on Finnish economy (in million euros)*

Figure 44 presents the Finnish changes in terms of output, carbon-dioxide emissions and employment created with Finnish investments excluded. The large differentiation between the size of change in impacts to the Finnish economy and the global economy is perceivable as Finland is manufacturing economy much like Sweden and Germany. The changes are even greater as only the Finnish downstream impacts are considered with 16.4 % and 24.6 % increase in output, 9.5 % and 19.7 % increase in carbon-dioxide emissions and 15.8 % and 23.3 % increase in employment created for the 50-50 and green and digital purchasing scenario respectively. Therefore, **in terms of the Finnish downstream impacts from foreign grant allocations more accurate allocation data would be detrimental for comprehensive analysis.** The expanded changes in impacts to the Finnish economy in the alternative scenarios are presented in table 20 below relative to the baseline scenario.

Table 20. *The impacts of alternative sectoral investment allocation scenarios on the Finnish economy*

Indicator	Scenario 50-50	Scenario green and digital
Output	16.4 %	24.6 %
Value added	15.9 %	23.8 %
GDP	15.8 %	23.6 %
Taxes	15.8 %	23.6 %
Energy (total)	15.1 %	26.8 %
Emissions (total)	10.1 %	20.1 %
Materials (total)	0.7 %	6.1 %

The alternative scenarios ran are very viable option, but still hindered by the sectoral aggregation in the model itself. If the specific green and digital investments could be applied directly to the specific sectors representing e.g., clean tech solutions or equivalent the results would tell different story as now the alternative scenarios were only able to be targeted to existing upper-level manufacturing and service industries that have strong foothold in the corresponding sectors. This specific level of detail cannot be applied directly in the large model but for further analysis the issue can be addressed by analysing sub-sectoral impacts or by creating a more detailed national model with more classifications if more specific national data was to become available.

7. ASSESMENT OF THE METHOD

In this chapter the findings of the thesis are reflected back on the research questions. The main research question being "*how to evaluate interregional effectiveness of foreign investments,*" the primary examination revolves around global value chains and the capability of the created construction to capture the expected impacts ex-ante. The simulated results are also briefly discussed to provide verification on the operationality of the model and to bring forth possibilities and issues of the method to be further addressed.

7.1 The validity and reliability of simulated results

The thesis was set to find out ways to evaluate the effectiveness of foreign investments. After MRIO analysis was recognized as the optimal tool for global value chain analysis during the literature review a construction was built. Throughout the construction process the target group of users, consisting of few case company experts, were consulted and changes were made based on their feedback resulting in e.g., the addition of consumption effects to the model. In the very end of the process, the graphical interface and the data inputs of the model were streamlined to minimize user error to ensure the consistency of results generation.

The construction built, a static global MRIO tool with subnational Finnish coverage, was used to analyse the internationally originating impacts of European Resilience and Recovery Facility grants on the Finnish economy, ergo Finnish grants were excluded from the main scenario and analyses. The implementation of a solution was done as Kasanen et al. (1993) denote that the usability of construction can be demonstrated with implementation of a solution. The specially restricted Finnish case was chosen as it is timely, relevant and demonstrates different mechanism of capturing value chain influences and as a brief similar analysis was done by the Finnish Ministry of Finance as a part of the national plan for the Facility grants use in 2021.

There are two main factors that heavily affect the results, the model itself and the scenario ran in the model. The first challenge in the result creation process was the creation of the initial scenario as no uniform assembly of by sector and country funding allocation was officially available for the case. Therefore, the initial data had to be collected from multiple sources and adjusted to right classifications for the model runs. Hence, aggregation can have notable impact on the results for three reasons – the sectoral aggregation made in combining the initial data for the model itself, the assumptions of sectoral aggregation made in initial scenario building from different data sources and the disaggregation of the initial scenario data from 19-sector classification to 56-sector classification and further to 67-sector classification. However, the errors are within accepted limits as transparent and systematic process was used in each of the steps, despite the sensitivity tests on the sectoral fund allocations of the scenario showing changes up to 27 % (table 20) i.e., **the reliability of the results is affected if differently classified initial scenario data is used**.

The second major variable-causer in the evaluation is the model itself as it is built on historical data. Therefore, many of the results created do not perfectly reflect today's economy as global value chains are always evolving. The major issue related to this is the effect of technological progresses on environmental impacts, as recent technological progress has cut the average environmentally negative impacts of production rather fast. This challenge is highlighted by the fact that if old carbon-dioxide extensions available (2012 release instead of 2019 release) is used for the model 26 % higher amount is received in the total simulation results. Thus, **the validity results hinders as they do not capture the most recent technological progress** and slight cautiousness should be applied when interpreting the results present-date and future impacts.

Another related flaw is the fact that most of the investments modelled themselves boost digitalization, sustainability, resource efficiency and green economy which have an environmentally positive impact that leads in future emissions cuts. If these impacts were to be captured additional data on specific investments and technologies related is required as much of the investments should be simulated as structural changes to the model core and the sustainability extensions. However, as the model imitates today's economy and as environmentally negative impacts are expected to occur all the while during these projects, the results can be seen as a very good baseline analysis for the investment phase impacts. Still, it has to be kept in mind that all of the environmental and social impacts cannot be captured with the model as data is lacking for the rest of the world region, denoting that regional sustainability impacts differ when applying consumption-based accounting. Regardless, as the actual results of the European Resilience and Recovery Facility realize throughout multitude of years the complete validation of the results would require a deep longitudinal study which is practically impossible as there are other ongoing projects and funding besides the Facility circulating both within EU-27 region and around the world that has an impact on virtually everything.

The validation of the actual results and reliability of the model is further addressed with a credible benchmark analysis. A similar yet brief analysis of intermediate impacts of the Facility on the Finnish economy was conducted by the Finnish Ministry of Finance as a part of the national plan for sustainable growth (i.e., the national recovery and resilience plan of Finland**). In the report the spill-over effects originating from other EU-27 countries were estimated to have a lifting impact on Finnish GDP of around in total 0.3 % in the timespan of 2021-2023, mostly due to gradual variation in Finnish exports. Similar result of 0.3 % rise in Finnish GDP was generated by the baseline scenario of the constructed model as well when the change was introduced on the same time period.** And although the total time period of Ministry's analysis is extended and includes external variables, the equivalence of the early-year estimates is intelligible as both of the models ignore the possible structural changes to the economy that the Facility can have. (Finnish Ministry of Finance, 2021) However, this thesis provides more extensive analysis on the matter than the publicly available ministry report on the intermediate impacts. Therefore, the similarities in distinct sectoral economic and socio-economic variables unfortunately cannot be compared. Regardless, the similarity indicates at the reliability and the validity of the created construction as it is capable of creating realistic impact projections for regional-national-international effectiveness evaluations.

7.2 Multiregional input-output modelling in global value chain and sustainability analysis

7.2.1 Method for evaluating interregional effectiveness

The literature review presents the top-methods for numerical effectiveness evaluation on different regional levels, majority of which are condensed to figure 5. During the process it was realized that currently CGE models represent the most cost-effective models for long-term local analyses but hinder when the scope is extended to global scale as trade-offs between the detail and the validity of results have to be made in order to keep the timespan of the study manageable. Another very good alternatives such as dynamic macroeconomic modelling, agent-based and stock-flow consistent models were disregarded in this thesis for similar reasons. More simple solutions such as basic financial analyses and balanced scorecard variants were ignored as they rarely capture the intricacies of global value chains.

Multiregional input-output modelling was chosen as the primary evaluation method for the study as **it has been established method for both public and private international economic and sustainability analyses for years** (see e.g., Bachmann et al., 2015; Chen et al., 2016). **It was also discovered to be the manageable** method in terms of accumulation of the needed knowledge and data needed for the creation of the global construction and the linking of it to an existing regional national model **in the timespan of the thesis**. **And as the results and the research process stands, MRIO**

analysis is a very good method for global value chain and sustainability analysis with the addition of qualitative reference marks.

7.2.2 Sustainability analysis with MRIO modelling

Multiregional input-output modelling captures the connections in global value chains and sustainability impacts related with multiple indicators. These indicator results can be used to estimate the available environmental resources and workforce requirements for projects in order to optimize the investment locations for national grants allocation as well as to support and promote the areas where intermediate demand spikes occur as a result of international investment needs. In the case of **the created construction** these cover basic economic, environmental and socio-economic accounts (see appendix B for the individual indicators) but **could be further extended with either additional sustainability accounts or with other calculated coefficients connected to the economic changes**. Some rather simple additions include extended material accounts based on Global Material Flows Database (see table 5), environmental extensions based on conversed Eora (Rodríguez-Serrano et al., 2017), Exiobase data to address matters such as biodiversity as well as emissions and more specific databases on environmental indicators like mercury (Zhang et al., 2019). Or in terms of socioeconomic extensions, consulting Eurostat's Pillar of social rights as Finnish Ministry of Finance (2021) or SHDB's social risks as Rodríguez-Serrano et al. (2017) are potential avenues for further model's coefficient development. Moreover, the created results could be tied to existing sustainability promoting frameworks such as the United Nations sustainable development goals within the model itself with the use of corresponding external data. As demonstrated **the extension possibilities are endless, but the model capacities limited. Hence, exclusion of indicators is inescapable.** Therefore, the global sustainability indicators are covered with only official WIOD (Genty, 2021; Timmer et al., 2015; 2016) and JRC data (Corsatea et al., 2019) in the global side of the construction.

For the Finnish side of the model extra indicators were used for economic and socio-economic accounts in terms of GDP, taxes, value added and improved employment estimates as the base research process for the specific values of multiple coefficients had already been made by the case company. Therefore, the subnational coefficients were leadable from these values and official Finnish statistics (Statistics Finland, 2021) with reasonable amount of extra research and number crunching. Similar extension are leadable for all the countries (besides RoW) in the model for indicators such as value added and GDP, but specific tax and other accounts are additions only advisable to be done in specific cases due to labour requirements and possibility of change in the values. This addition would be very relevant for the case of similar evaluations for all the individual EU-27 countries impacts as the current global model is already able capture the basic sustainability impacts for all the countries within the model. In fact, the basic economic, environmental and socioeconomic impacts for all of the countries that the model covers were created as a part of the process of simulating the Finnish impacts as demonstrated by figure 20 and figure 45 presenting the total economic impact shares by available countries in the model (note the high impact on e.g., Chinese and the US economy).

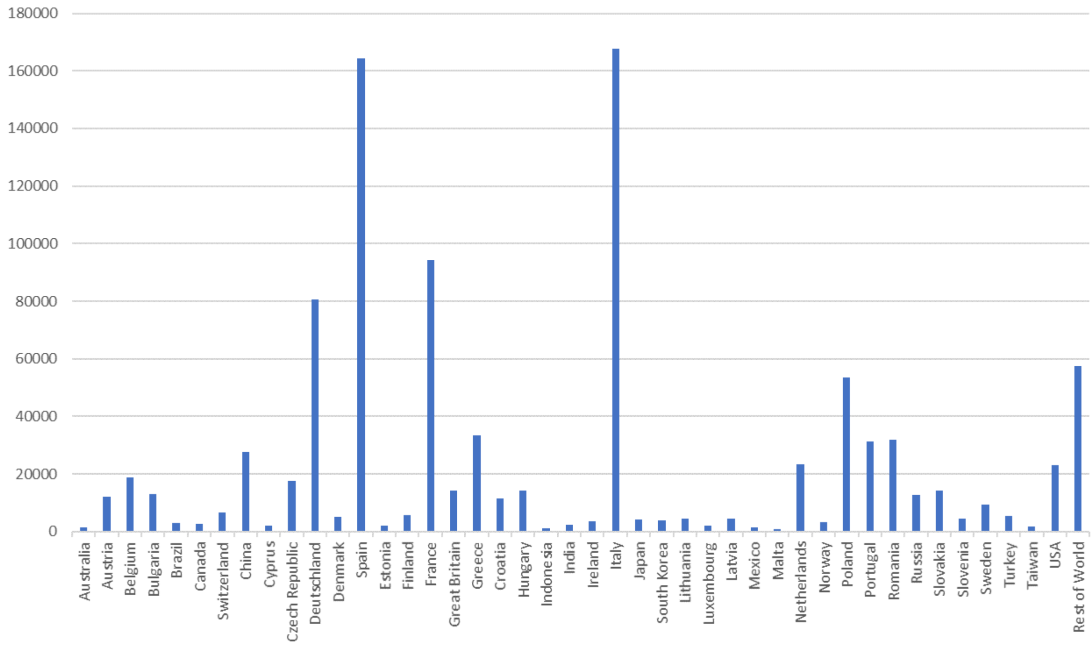

Figure 45. *Total output increase by country (in billion euros)*

However, the total analysis of all of the simulatable impacts is laboursome and rather fruitless as more intricate analyses have been already created by governments themselves as part of the national plan building process with more detailed initial data (European Commission, 2021). Also as detailed and subnational country specific model exists currently only for Finland, the Finnish results would have had to been levelled down to be more comparable to other results in terms of the indicators. This is highlighted by the fact that the global-module was used for the Finnish impact inputs to create comparable results. This was done because if the changes were introduces directly to the more detailed Finnish subnational-module, the Finnish national impacts were economically 18 % and socioeconomically 19 % higher detriment to other countries as the difference in total global impacts differed only by less than 0.30%. In other words the Finnish subnational-module regards the Finnish originating value chains to be less global than the base WIOD-model. This is explained by the fact that the Finnish module is built on most recent data on the state of Finnish economy and interactions, whereas global side of the model is based on harmonized 2014 data.

As more detailed analyses exist for the EU-27 regions **the model presents an opportunity to address the distribution of global sustainability impacts**. Figure 45 demonstrates that many countries outside of the European Union receive more impacts than the EU-27 countries themselves, denoting that the regions do not only gain benefits of the Facility but also contribute to the scheme by creating emissions and other environmental impacts. As differing satellite accounts exist for all of the regions, **analysis of the global impact data presents valuable information on minimizing the harmful environmental impacts and promoting more sustainable and socio-economically friendly solutions thorough analysis of global value chains.** Therefore, the environmental and social information can serve e.g., as a basis for greener procurement that is in line with the green economy sentiment of the Facility.

By further addressing the global impacts, observations on global or regional development targets can be drawn by targeting the developmental impacts and resources on industries that clearly participate actively in linchpin value chains. In this case, a clear example is the mining and quarrying industry of the rest of the world region (see appendix E) that is recipient of second to most economic impacts of the Facility throughout the whole world in spite of being allocated zero euros directly to. Consequently, it is the main contributor in terms of material impacts as it produces most of the minerals needed for the investments and intermediate production. For the purposes of effective analysis the material indicators should however be extended to cover individual raw materials or material groups such as aluminium, iron ore or cobalt. This in turn requires laboursome work on manipulation of material information, making it an excessively broad topic for the thesis but a relevant issue to be addressed in future research.

However, what a short global value chain analysis on the topic presents, is the opportunity of the Facility investments to address the issue by e.g., allocating more of the investments and procurement towards recycling technology and circular solutions instead of the mining and quarrying industry. This in turn would strengthen the position of Finland in terms of intermediate impacts as the country has a strong foothold in both recycling solutions and the recovery of rare minerals and ore business. In fact, contributing more of the money towards these sectors detriment to the mining and quarrying industry would represent the current economy better as circular economy and recycling solutions have become common topics and presented more viable solutions in recent years. Unfortunately as the base data for the global model is based on 2014 statistics this cannot be currently effectively modelled as this requires major changes to the basic structure of the model – especially as the simulated mining and quarrying industry impacts are indirect. Therefore the analysis of more profound sustainability opportunities is currently limited to qualitative level.

Finally, **the results and analysis clearly display the two-fold role that sustainability promoting investments have. Majority of the simulated impacts had positive impacts on one or two sustainability dimensions and negative on one**. For example, many of the investments simulated promote social equality and enhance the digital capabilities of people but create harmful environmental impacts at the same time. And though, the model is able to present the changes on these investments' sustainability parameters on a regional and sectoral level, the final assessment and decision over sustainability trade-offs remains at hands of policymakers.

7.2.3 Global value chains influence on investment impacts

The numerical analysis of global value chain design presented in chapter 6.4 brought forward that both the altering of EU-27 grants allocation and the subnational Finnish allocation of grants have ample impacts on the Finnish national economy whereas the total global impacts remain largely the same. This is the result of value chain connections as though the trading partners to certain intermediates may change, usually roughly the same amount of goods is still needed to meet the final demand. Therefore, **global value chain analysis can display opportunities to capture more of the positive impacts to oneself**, detriment to the competition or in this case detriment to other nations.

In the Facility case global value chain analysis was done by altering the shares of large investments by nations or the sectoral distribution of grants. This demonstrated that **by slightly altering the allocation of funds to the trading partners economy, previously more unattractive trading partners can become more attractive options** as displayed by the controversial case of Ireland. Keeping on with the idea, to capture the ultimate benefits of global value chain connections, **the GVC analysis should be extended after discovering the initial impacts by taking a look at individual nations and sectors input impacts thorough outcomes of nations and sectors one by one to find out the most prominent foreign investment locations**. In practise this analysis could be ran with the current model but it would require a lot of time as the inputs would have to be fed one by one 2 464 times unless the specific nations and sectors to be studied were recognized and targeted. Still this analysis would fail to capture all the intermediate connections of circulating impacts as the model captures mainly the total impacts by parameters meaning that it does not separately capture the small shares that run back and forth between partners multiple times as displayed in figure 3. However, this could be somewhat discovered by analysing the different shares in the matrices used to build construction. Alternatively, a tool with more inbuild features such as the Trade-scan v.2 (Román et al., 2020) could be used for similar uses as it allows users to analyse final impacts that set nation or grouping of nations has via certain intermediates trade partner, taking the global value chain analysis one step further. In theory similar features can be built on the constructed model as well, but as it is already currently running at the very limits of the software capacity it might not work in practise. Therefore, using specialised software (GAMS, Gempack, Matlab and others) would be beneficial in terms of further GVC analysis.

Global value chain analysis is beneficial for all foreign investment analysis though this thesis mainly covers the European Union Recovery and Resilience Facility. The constructed model (and further analyses) could be well adapted to suit the needs of a more specific investment such as a paper and paper products industry venture in Brazil for example. In practise this could be done as simply as assembling new relevant inputs with right sectoral allocations for the scenario and feeding them into the model to get the basic outcomes. The basic input could be simply the allocation of money to *the paper and paper products, construction and machinery industry* of Brazil but as in reality investments do not follow the average trade structures in the data, more distinct sectoral allocation should be made especially if it was known that some of the goods would originate from certain trading partner back home to e.g., justify government subsidies for foreign projects. Similarly, in the case of Facility the grants will most likely distribute differentially from the scenarios ran as much of the green and digital investments favour the Finnish business environment with a lot of prominent firms operating in the field of cleantech and sustainability. Therefore, it might be more justified to take part-in the European Union Recovery and Resilience Facility than this assessment gives it credit with only minor 0.3 % GDP increase from the internationally originating investment-phase impacts. To further add, Finland will also benefit from the recovering European economy as stated by the Finnish Ministry of Finance (2021) and the new state of global economy as the post-investment phase global value chains will most likely favour the green and digitalized economies more than before.

7.2.4 Statistical modelling in interregional sustainability analysis

Multiregional input-output modelling worked very well in the example case as the results were within the range of initial estimates and comparable to an official benchmark. The level of result detail desired was achieved with the created model as the three pillars of sustainability (economic, environmental, social – or socio-economic in this case) were addressable directly from the results with sufficient detail, though this could be further enhanced. The level of sectoral and sub-national detail initially pursued (56 and 63) was surpassed with the addition of more detailed subnational-MRIO with 67 sectors that is based on most current Finnish economic equilibrium and interactions data. However, the level of detail beyond 56 sectors was only available for the Finnish module. **Extending other nations of the model to sub-national detail** is possible in theory but lamentably it would require a lot of data manipulation and research. Regardless, this **should be considered if similar analysis was to be done for other individual nations as the analysed results presented notable findings on the impact of sub-national value chains on national final results**. The approach used in the current model with solving of the problem with different sectoral aggregation between different classifications could be applied for these cases as well, mainly consisting of using averages from trade data (Palm et al., 2019) and the existing model data. And although this is deteriorated by the fact that factually disaggregation itself creates more uncertainty in terms of validity, in practise it provides more useful results – as e.g., in case of the simulations the start data could have been rather directly allocated under the seven flagships areas of the Facility (see 4.3.1 and European Commission, 2021), but then the results would have been at the same level of detail. That said, the simulation runs themselves – the statistical effectiveness evaluation process – could have been upgraded in three ways.

First, the results could have been introduced to the model itself at different timespans as in the Finnish ministry of Finance report (2021) to capture the value of money. However, this would have only impacted the results slightly due to the short time span of the investments and the current state of economy. Also, the individual funding is distributed in varying time frames, so assumptions about this would have had to been made then, and impactful assumptions were to be avoided when possible.

Second, the structural changes to the economy could have been introduced to the scenarios with addition to the first upgrade. However, in this case even larger assumptions would have had to be made in order to estimate the annual change to economy as merely assuming the economy to follow the introduced yearly investments has potentially significant impact on the results – especially as in reality much of the money is directed to niche sectors. In mathematical terms, this refers to creating new intermediate and other matrices based on yearly investments. However, the restrictive factor for this process is the processing capacity of the current software as it would make the simulations unsmooth for such large amounts of data. Still, some of this impact could be avoided by creating additional industries to the model similarly to Malik et al. (2014) to e.g., energy sector to promote the more sustainable solutions but this in turn would again require large assumptions and vast amounts of labour or specialized software to be used such as the AISHA tool (Wang et al., 2017).

Third, as the focal point of the study is the Finnish impacts, the analysis could have been connected partially to a CGE-analysis to capture the local long-term and wide-spread economic impacts in addition to the current results. This is a very interesting and important prospective analysis as it allows capturing of the realer local impacts and possibly even the negative impacts to competing sectors that results from investing to more greener and digitalized solutions. And as the results now only cover one-time snap-shot of the Facility, thus the effectiveness evaluation is limited to monetary flows during investment phase (2021-2013) denoting that if no structural market-based change happen the economic impacts will disperse after the investment phase, additional CGE-analysis (or similar) could also cover the post-investment phase impacts.

Besides introducing CGE analysis on top of the MRIO analysis other possibilities to the additional and even complete analysis of the Facility impacts exist. This can be examined by taking a second look on the figure 5 that displays the different impact modelling approaches capable of global value chain analysis addressing both local and global impacts. These differing modelling approaches present distinctive traits that can be used to make the evaluation more extensive, specific or dynamic but require considerably varying amounts of labour and expertise to conduct. Table 21 brings back the modelling approaches presented in figure 5 with analysis on the approach's applicability to the evaluated scenario with exclusion of MRIO and EE-MRIO approaches as the constructed model is in fact variation of EE-MSIO or EE-SNAC-MRIO.

Table 21. *Analysis on the applicability of different modelling approaches on the restricted case*

Approach	**Usability**	**Amount of labour**
Static models		
LCA	Additional analysis of the lifetime environmental impacts of the investments on top of the MRIO.	**Moderate** amount of work if targeted to specific industries.
Nested MRIO	The complete analysis could be individualised between distinct countries and sub-national regions with access to local trade statistics with the EU following approach of Chen et al. (2016).	**Large** amount of work requiring data manipulation and building of new partial model.

Dynamic models		
CGE	Additional CGE analysis built on MRIO results and scenario inputs would provide more realistic results on local level if the right model was utilized as it would allow the addition of different socio-economic factors to the simulations such as taxes (Mbanda. & Chitiga-Mabugu, 2017).	**Moderate** amount of work if access was granted to an existing model for the Finnish economy, **large** if existing base model such as the PEP-model had to be adapted for the purpose.
SCGE	Spatial CGE model and analysis on the whole scenario would be very good tool for use hand in hand with the MRIO results on large regional level such as the EU as it could allow rough targeting and optimization of subnational economic impacts.	**Minor** amount of work if access was granted to an existing model for the European economy such as the RHOMOLO model (Lecca et al., 2019) otherwise very **extensive.**
DCGE	Dynamic systems would be very good tool for additional (or complete with the right tool) analysis following the lines of CGE analysis benefits with addition of clear time-bound impacts, consequently allowing the effective analysis of introducing the Facility grants gradually to the economy and accounting for structural changes caused by the investments.	**Moderate** amount of work if access was granted to an existing model for the European economy such as the FIDELIO model (Rocchi et al., 2019), **large** if new was to be constructed.
DEM	Introducing dynamic economic models and functions to the existing analysis or Finnish module would be plausible and benefit the analysis but too unified if entered to the global side of the model.	**Minor** amount of work with proper expertise but **extensive** amount of work without existing functions or specialized software for the partial analysis.
DSM	Creating a dynamic systems model for Finland to analyse the impacts thorough set indicators would generate most detailed data in terms of sustainable development.	**Extensive** amount of work and access to a base dynamic systems model required, **not worthwhile**.
Hybrid models		
CGE-MRIO	Following lines of Nabernegg et al. (2019) and creating a CGE-MRIO hybrid model would	**Extensive** amount of work whether external help was got

	undoubtedly produce very interesting and relevant results for the whole scenario as some of the time-inducing and societal impacts could be covered with the model and analysis but it would require use of alternative database with CGE applicability such as GTAP.	from GTAP experts, would also require the purchase of most recent GTAP version. Perhaps plausible for other databases also with vast amounts of work.

Combining CGE and MRIO to one harmonized model would in theory contribute the most accurate results for the case of the Facility. However, as Nabernegg et al. (2019) demonstrated that the combination of methods to one plausible model that produces convincing results it is still very much in the development phase and applying similar methodology to the Facility scenario would require undefined amount of work. Seeing similar analysis in the future is not impossible as GTAP is producing more and more compatible social accounting matrices for computable general equilibrium analysis though it is very unlikely to see one used openly on the complete case as Malik et al. (2019) predict that global value chain use of MRIO modelling is going to advance towards more specific city-scale models eligible for sustainability analysis, similar to the pioneering transnational modelling by Chen et al. (2016). However, if reliable whole world encompassing CGE-MRIO hybrid-model did exist the input data used in the constructed model could be most likely fed into the model with few alterations. These results could be further compared to the results of constructed MRIO model and would grant major information on the impact that distinct existing economic factors, not covered by the current model, has on the actual results.

More realistic options on additional analyses of the scenario are achieved with use of either CGE, DCGE or SCGE models as the use of the other categorized models in table 21 would result in either swaying (DEM), minor and specific (LCA, Nested MRIO) approximations or be too arduous tasks to be undertaken (DSM). However, the reasonable utilization of additional or complete CGE analysis would require an access to an existing software either on EU or Finnish scale. As the focal point of the thesis is the Finnish impacts the access in question refers to either RegFin model and its dynamic variant (University of Helsinki, 2021), one of the Finnish Ministry of Finances models or equivalent. These results should however be mainly used to approximate the validity of the constructed MRIO models local results or to balance the results to better capture the local impacts as the current inputs and results are very easily proportionable.

The constructed model is evidence that by linking existing geographically restricted multiregional input-output models to models based on large global databases, global value chains can be analysed with good accuracy. Therefore,

implementing a sub-national model inside of a global model might not be the best option in short run, despite the approach gaining more popularity in recent years (see Bachmann et al., 2015; Christis et al., 2017; Meng et al., 2018; Wang et al., 2017; Zheng et al., 2019). By addressing the anomalies in analyses with these linked models' large singular impacts such as fading of large organisations or commercial blockages can be quickly solved with analysis of current state of economy by comparing more recent local model and the national side of the global model instead of having to map out historical changes in the economy. However, **inserting a sub-national table within a global model is beneficial if the analysis is environmental one and the model core is a material one instead of being monetary** similarly to Piñero et al. (2020). *This implementation decreases the impact risk of incorrect material flows between sectors as abbreviated material flows would have large impact on other extensions if the flows were to be subdivided and grouped even slightly wrong – 100 ton difference in comparison to 100 000 euro difference within specific service (and other) sectors has a vast impact on sectoral results – if linked models were used and differences between the sectoral classifications of the models existed.* **Additionally, implemented models are a good option in the long run as development of more and more precise subnational models within global models allows the global databases to extend to cover more grounds in the future**. In terms of practitioners, this development is best left out for academics and other experts that focus on building of the global models and combining statistics as the existing large and linked models are the most time-effective solutions for now.

Furthermore, as the amount of available data increases and more individual databases become publicly available more precise sustainability analyses can be done applying statistical modelling. This progress is especially important in terms of more distinct social indicators as most of the global MRIOs including WIOD only cover employment and related monetary impacts. The progress is pivotal in order to better address central social dilemmas such as gender equality, standard of living and healthy lives (United Nations, 2021) thorough numerical indicators that can be connected to global sustainability frameworks such as the sustainable development goals (table 1). In addition, to creating and combining new satellite accounts and databases, **the research process has presented a clear need for uniform locations to find relevant coefficient extensions and satellite accounts for sustainability indicators**. Naturally, there are many global MRIO models with own satellite accounts, but individual researchers do also modify existing statistics to be their own satellite accounts for the research purposes (Zhang et al., 2019) that are usually deployed in supplementary material of published articles that are not accessible for all practitioners and even researchers or difficultly discoverable on the web sites of large organisations (Corsatea et al., 2019). Therefore, uniform location for both up-to-date existing MRIO databases and corresponding satellite accounts would be beneficiary. Slightly similar efforts have been seen in form of the IElab (Malik et al., 2019) though it focuses more on the streamlining of MRIO building process than the assembling of statistics and databases. Another developmental focal point within global MRIOs is the updating of the models. For most of the publicly available free databases the update intensity is either undefined or non-existent and for the chargeable databases the update intensity is rather low (Remond-Tiedrez & Rueda-Cantuche, 2019). In terms of practitioners, updating existing databases can be even more important than the creation of new MRIO databases (most recently FIGARO) as existing linked models – such as the constructed model – could be adjusted to the updated datasets far more effortlessly than to be built on completely new datasets. One good example of steadily updated global MRIO databases exists by the OECD but the datasets lag behind others in terms of available satellite accounts and are therefore not the optimal choice for complete sustainability assessments.

To promote global sustainability – in addition to new satellite accounts and databases becoming public – tools for global value chain analysis such as the Trade-scan should become widely available for public use in future. This would allow both the researchers and practitioners to conduct quick and easy analyses for specific purposes. This advancement would see most benefit for minor sustainability and value chain analyses in hands of small and medium companies. The organisations would be able to assess the sustainability impacts of their value chains beyond the closest suppliers and adjust sourcing strategy and operation accordingly, towards more sustainable direction. This applies to other models presented in figure 5 as well, though most of these modelling techniques require more expertise than e.g., Trade-scan per se. Naturally, this consumes commissions from expert organisations, hence reducing the total economic activity and societal income within regions but potentially promotes environmental and social sustainability to a significant degree.

8. CONCLUSIONS

This chapter presents the main findings of the research and reflects them on the objectives of the research. The created construction is evaluated and its applicability, validity and potential development points are addressed. The theoretical and practical contribution of the thesis is appraised and recommendations are given for both the case company and practitioners considering conducting similar analysis. Lastly, limitations of the research are compressed and implications on future research are presented.

8.1 Main findings

The research was set to find out *1) how to evaluate the interregional effectiveness of foreign investments, 2) the sustainability impacts traceable with global value chain analysis, 3) influence of global value chain design on the viability of foreign investments, and to 4) further develop existing national IO-tool of the case-company to cover global value chain impacts in detail*. The research was expected to both produce information and suggestions on available solutions and approaches for global value chain analysis and to construct a working statistical model to appraise global value chain connections and sustainability impacts. The central thought behind the construction was replicability of the process and easy adaptation of the tool to cover additional regions if necessary. The model was tested on upcoming EU-27 investment called the Facility.

Results of the Facility √. The results simulated suggest that investment phase impacts alone are not able to justify the Finnish involvement in the European Recovery and Resilience Facility agreement.

The study was carried out for an expert organization in effectiveness evaluation and impact assessments. Therefore, the model itself is restricted for the use of the case company but the results and construction process are universally applicable for the most part. The thesis estimates that the investment phase of the Facility will introduce 1,8 billion euros of momentary output to the Finnish economy in the time period of 2021 to 2023 when only the internationally originating impacts are considered. This represents a total increase of 0.3 % in Finnish national GDP, a similar result to the Finnish Ministry of Finance estimate for the same time period investment phase impacts. Globally the Facility will momentarily constitute an impact of nearly one trillion euros increase in global output and introduce need of 6,7 million FTEs to the labour market. Global value chain analysis suggests that most of the economic impacts resonate globally to the construction, energy and service industries but more towards the manufacturing sectors in Finland.

First research question √. Literature review presents relevant statistical approaches to IO-based effectiveness evaluation. These modelling approaches are collected to figure 5 and further addressed in table 21.

This thesis brings forth the idea of using global value chain analysis to optimize both the local and global sustainability impacts of ventures thorough the eyes of an investing country and examines the applicability of different statistical methods to global effectiveness evaluation. Numerous approaches were identified during the literature review and based on the global and local scope of the wanted analysis CGE and MRIO modelling were recognized as the top approaches for the type of the desired analysis in a restricted timespan. Based on further scrutinization of the models capability to address wide range of sustainability indicators, MRIO modelling was chosen to be further method explored and working application of global multiregional input-output model with sub-national linkages was created for the Facility assessment. However, it was recognized that in future dynamic hybrid models will become the best option for similar analysis as global input-output and sustainability indicator databases evolve (Allen et al., 2016; Malik et al., 2019; Nabernegg et al., 2019).

Second research question √. All three pillars of sustainability can be addressed within scope of global value chain analysis. However, the lack of available data on social sustainability and impact of technological progress on environmental satellite data presents challenges for accurate and timely impact assessments.

The statistical analysis indicated how MRIO models can cover multiple sustainability dimensions within a sole model thorough use of existing satellite accounts and coefficient databases. Creating case-designated satellite accounts was recognized as a viable option for specific analyses, but requires significant amount of labour (Zhang et al., 2019). Therefore, creating of collective location for satellite accounts and coefficients manufactured by researchers and practitioners was identified as a prominent potential update within the field. In addition to creating overall data on sustainability matters, the models are able to address the sector-specific impacts and recognize the integral sectors in global value chains that constitute heavily to the results. In this thesis, the mining and quarrying sector of rest of the world region was identified as integral sector in global production that constitutes much of the material impacts in the case analysis. As RoW category consists mostly of developing countries where both the technological progress and working conditions can be seen lagging behind within the industry, special actions should be taken when considering individual investments of the Facility or global developmental projects. And although the environmental factors of the industry could be well analysed with extended environmental satellite accounts (e.g., with Exiobase) the lacking social accounts for RoW region makes the analysis challenging. Hence, creation of more extensive social indicators is an integral update in terms tracing of sustainability impacts in global value chains that is vital for consumption-based responsibility approach and to the ecological theories building on it (Piñero et al., 2020; Stöllinger, 2021)

Third research question √. Global and sub-national value chains have a clear influence on final sustainability impacts of location bound ventures. These impacts cover the sectoral and interregional impacts in addition to sustainability ones.

The analysis has evidenced the significance of global value chains on both global and local results. Modelling different investment scenarios displays that by averting Finnish procurement efforts towards developed countries such as Sweden or Germany instead of average global value chain avenues, investment constitute to less environmentally harmful impacts (figure 34). Besides the global value chains, subnational ones have a clear impact on the results as well, demonstrated by the analysis of Finnish major regions (table 21), when considering nation specific impacts. Therefore, using similar value chain analysis is beneficial application to ex-ante effectiveness evaluations already in the investment planning phase when project location has not been decided yet, if possible, as currently the majority of local impact assessments are done after the location has been decided. In future, these local-global-local connections are more and more traceable as methods and databases evolve, and a leap in the MRIO analysis can be seen when more city-specific data becomes publicly available (Chen et al., 2016; Malik et al., 2019)

Fourth research question √. A global multiregional input-output model with Finnish sub-national coverage was created. This tool can be used to analyse both Finnish originating investments to global environment with alternative import distributions and internationally originating investments to the Finnish environment with extended national economy indicators.

Another major advancement in MRIO modelling besides the enhanced location-based data is advancements in sectoral disaggregation of large databases and models. In this study models with 67, 63 and 56 industry classification were connected into a working model with existing sectoral output distributions and trade data. This presents a slight contingency to accuracy of the results that would be amplified if sectoral aggregation was to expand in future. However, as more accurate sectoral targeting of impacts enables the study of exact investments and phenomenon, applying more extended aggregation to the models such as the constructed one should be done when possible. In terms of the constructed model, many other upgrades were recognized thorough the research process on sustainability, global value chain and operationality matters that have been condensed in figure 46 below.

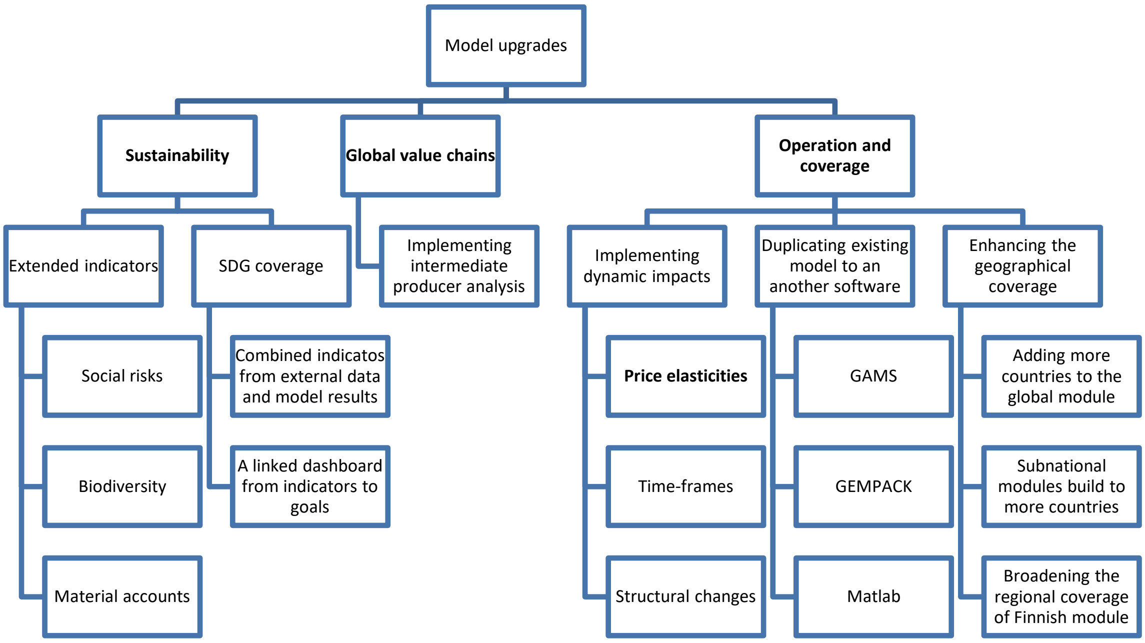

Figure 46. *Potential upgrades to the constructed MRIO model*

At its current state the model is very capable to address various global and local impacts as is. It is also very extendable to cover many other sustainability matters that are not covered currently directly in the model. With slight adjustments it can also be fitted to cover sustainability impacts of more specific Finnish sub-regions as well. By following the construction process creation of more linked subnational-modules to the current model is also possible if sufficient initial data is available. However, as technology and global economy advances the models accuracy to cover current events decreases over time. Therefore, the model should be updated when more recent data becomes available in WIOD form as the current model will become outdated in few years.

8.2 Academic contribution

Global MRIO modelling with subnational coverage presents unique way of tracking connections of region-specific impacts to global demand that has seen new adaptations in recent years (Christis et al., 2017; Meng et al., 2018; Palm et al., 2019; Piñero et al., 2020). This thesis presents one of the few Finnish analyses to date focusing on GMRIO modelling and is in fact the only publicly available analysis covering subnational-GMRIO modelling thorough all three pillars of sustainability in Finland as far as the researcher is aware. Concurrently, it is the second publicly available analysis on internationally originating impacts of the Facility on the Finnish economy, first one being the Finnish Ministry of Finance report (2021) that does not present the results as broadly and in detail as this report. Therefore, the result present integral approximations of the short-term demand needs entering the national economy for researchers, private organizations and regional public administration. Consequently, the results detail and the construction process of the thesis serve as a reference mark for future model developers that wish to analyse impact of grand projects to the Finnish national economy on a detailed sectoral level.

The thesis verifies the challenges that sectoral aggregation and the timeliness of data present to MRIO recognized and researched by multiple researchers prior (de Koning et al., 2015; Piñero et al., 2015; Steen Olsen et al., 2014; Tukker et al., 2018). Alternative to majority of current research that focuses on different sectoral aggregation within databases and models, the study analyses sectoral aggregation thorough uncertainties in initial scenario building data which is often disregarded since more specific information exists. It was found that even slight differences in distribution of very aggregated data can lead to variations of up to 30 % on a national level in realistic scenarios. Like Tukker et al. (2018) the influence of outdated data of the database was taken notice of but only addressed qualitatively as no practical solutions for bypassing the issue was found.

This study rounds up recent theory, databases and working solutions of impact modelling and presents an example analysis. This comprehensive of scope is uncommon for the field that generally focuses in either model development and analysis or evaluations of issues and recent progress related to the method, databases and modelling. Therefore, the thesis presents a quick and unique channel for newcomers to interregional effectiveness evaluation to familiarize themselves with some of the most important topics on the field.

8.3 Practical recommendations

For the case company, combining global value chains to Finnish subnational models is now effortless as the process can be done with quick and minor adjustments to the baseline model, though this does require familiarization with the model and some expertise in IO modelling. Other add-ons to the constructed model such as extra-countries, additional sustainability indicators and dynamic features should be done case-by-case as this requires time and effort. Considering of using an additional side CGE-analysis alongside the constructed model and applying GTAP in international impact assessments is recommended as it has been demonstrated in current literature that it allows the construction of hybrid CGE-MRIO models (Nabernegg et al., 2019). Another development avenue is the creation of similar models on other GMRIO databases as Exiobase and Eora present opportunities for more detailed environmental analysis, and the OECD tables are updated frequently.

Practitioners should consider the global value chain links and international impacts along with the local impacts when possible. Most simply this can be done by utilizing a separate GMRIO model that can be used to draw reference marks and sourcing options alongside the local impact estimates. Still, connecting of the separate national and global model is recommended if possible. The global MRIO datasets can also be utilized in the creation of local sustainability indicators if national data is not easily accessible or project is otherwise restricted as these indicators can be drawn from available national averages.

The Finnish policymakers should carefully consider the allocation of the Facility grants to gain most of the available funds. By distributing the funds to different major regions and sectors in a particular way and by channelling industrial procurement towards close trading partners with feedback value chain links the total Finnish socio-economic benefits can be maximised without increasing environmentally harmful impacts.

8.4 Limitations and future research proposals

This study was conducted for the needs of an expert organization on the field of effectiveness evaluation. This allowed the researcher an access to an existing sub-national model of Finland that is not publicly available. Therefore, creation of similar sub-national modules to be connected to a global MRIO as described in this study can become a challenge for practitioners wishing to emulate the process presented in this research.

The sub-national Finnish module is based on more recent data than the global base model. This caused incompatibilities within the Finnish intermediate value chain flows between the modules as the more recent data considers Finnish value chains to be more nationally circulating than international compared to historical global trade data. Therefore, a consideration is advisable when comparing the Finnish results to global ones. Furthermore, the old global value chains highlight some industries excessively i.e., the mining and quarrying sector of RoW that affect the result as well. More so, uncertainty is caused by the fact that the complete model is static, denoting that the changes that happen in the structure of economy within the investment period (2021-203) due to momentarily disruptions to the economy and global value chains are not covered by the analysis. These in fact can have notable impacts on both the results of the investment period impacts and the post-investment phase economy. Furthermore, as **the analysis is restricted to investment-phase impacts it should be extended to cover the post-**

investment phase impacts with the structural changes taken into account. However, this supplementary analysis in addition to further analysis of the investment-phase impacts with confirmed allocation of last 30 % of grants and the requested national loans with more disaggregated data on the specific green and digital investments are more **recommendations for future research** than limitations of the study. Consequently, the validity of the results and partially the constructed model cannot be fully addressed until the real-world impact realize. This in turn, requires a profound longitudinal study that was infeasible in the time-frame of the research process. Finally, three new avenues for future MRIO research were identified:

1. ***Mapping and composing of all publicly available satellite accounts – directly or with minor adjustments – applicable to global MRIO modelling***
2. ***Constructing a global MRIO with multiple linked sub-national modules and estimating the operationality and reliability of the model***
3. ***Estimating the magnitude of error that using survey- or national accounts-based historical datasets has on impacts of present-date ventures by comparing scenario results with different datasets on annual national and global state of economy***

The proposed future research recommendations facilitate holistic MRIO model construction process towards more reliable and swift direction. Hence, they serve the needs of both researchers and practitioners around the globe.

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APPENDIX A: MATRIX OF MODELLING STUDIES

Article heading	Authors	Publishing type	Model type	Model name	Modelled case	Timespan	Pivotal impacts	Impact methodology	Location	Base of assumptions	Main data inputs	Wider Impacts
Using a new USA multi-region input output (MRIO) model for assessing economic and energy impacts of wind energy expansion in USA	Faturaya, F. Vunnava, VSG. Lenzen, M. & Singh, S. 2020	Scientific article	Static	EE-MRIO	Energy investment	After use (1 year)	Energy consumption, resource demand	Change in demand	USA	Shocks based on JEDI, Leontieff IO-logic	Uslab, NREL, MECS (survey)	Economic, environment
Assessing the three sustainability pillars through the Framework for Integrated Sustainability Assessment (FISA): Case study of a Solar Thermal Electricity project in Mexico	Rodriguez-Serrano, I. Caldés, N. Rúa, C.D.L. & Lechón, Y. 2017	Scientific article	Static	EE-MRIO, FISA Framework	Energy investment	Project phase & plant operating	Sustainability	Change in demand	Mexico	Leontieff IO-logic & previous studies	WIOD, Eora, SDHB, ESTELA, previous studies	Socioeconomic, environmental, social
Growth and employment impacts of public economic infrastructure investment in South Africa: a dynamic CGE analysis	Mbanda, V. & Chitiga-Magubu, M. 2017	Scientific article	Dynamic	CGE	Public infrastructure investment	Accumalating (30 years)	Economic growth & employment	Change in supply (and demand)	South Africa	Techniques applied in previous studies, economic theory	SAM (SA), StatsSA, SARB, National treasury, previous studies	Economic
Simulating the impact of new industries on the economy: The case of biorefining in Australia	Malik, A. Lenzen, M, Ely, R.N. & Dietzenbacher, E. 2014	Scientific article	Static	Hybrid IO-LCA	Establishing new industry to country	Sequantial	Market structure	Change in technology	Australia	Leontieff IO-logic, previous studies, change modelled with a benchmark	Eora, IBGE	Economic, socioeconomic
The importance of studying inter-regional spillover effects of European policies: application of the RHOMOLO model for Poland	Lecca, P. Salotti, S. & Conte, A. 2020	Working paper	Dynamic	SCGE	Investment policy	Accumalating (50 years)	GDP	Change in supply (and demand)	EU	Economic theory, previous work	Eurostat	Economic
Policy coherence to achieve the SDGs: using integrated simulation models to assess effective policies	Collste, D. Pedercini, M. & Cornell, S.E. 2017	Scientific article	Dynamic	Dynamic systems model	Energy investment policy	Accumalating (15 years)	Life expectancy, access to electricity & years of schooling	Change in technology	Tanzania	Previous work, historical data, literature	World Bank, IEA	Socioeconomic
Potential effects of scaling-up infrastructure in Peru: a general equilibrium model-based analysis	Montaud, J-M. Dávalos, J. & Pécastaing, N. 2020	Scientific article	Dynamic	CGE	Infrastructure investment policy	Accumalating (15 years)	National economic impacts	Change in supply (and demand)	Peru	Previous studies, economic theory, author estimates	SAM (Peru), INEI (survey)	Socioeconomic, economic
Assessing spatial equity and efficiency impacts of transport infrastructure projects	Bröcker, J. Korzhenevych, A. & Schürmann, C. 2010	Scientific article	Static	SCGE	Infrastructure investment policy	20 years from benchmark year	Trade cost reductions	Change in technology	EU	Economic theory, previous studies	GTAP version 6, Eurostat, ETIS BASE, RRG GIS, literature	Economic
Transnational city carbon footprint networks – Exploring carbon links between Australian and Chinese cities	Chen, G. Wiedmann, T. Wang, Y. & Hadjikakou, M. 2016	Scientific article	Static	Nested EE-MRIO	Emission reduction project	After changes	Emissions	Change in technology	Australia & China	Leontieff IO-logic, previous work	Previous studies, Eora, GCCSA, NBS	Environmental
Triple bottom line study of a lignocellulosic biofuel industry	Malik, A., Lenzen, M. & Geschke, A. 2016	Scientific article	Static	Hybrid IO-LCA	New production options to country	After changes	Triple bottom line impacts	Change in demand	Australia	Leontieff IO-logic, SPLD, previous studies	ABS, AIP, NREL, BREE, DCCEE previous studies	Social, economic, environmental
Evaluating International impacts of China-specific shocks in an input-output framework	Simola, H. 2019	Discussion paper	Static	IO-framework	Demand, supply & tariff shocks to Chinese economy	Short term effects after changes	Value added & GDP	Change in demand (and supply)	China & RoW	Previous stuedies, Leontieff IO-logic, economic theory	WIOD	Economic
Mining and petroleum boom and public spending policies in Niger: a dynamic computable general equilibrium analysis	Sangare, S. & Maisonnave, H. 2018	Scientific article	Dynamic	CGE	Reinvestment policy	After changes (1 year) and (4 years)	Economic growth & employment	Change in demand (and supply)	Niger	Previous studies, PDES, INS	SAM (2012 Niger), previous studies, INS	Economic
National Policies for Global Emission Reductions: Effectiveness of Carbon Emission Reductions in International Supply Chains	Nabernegg, S. Bednar-Friedl, B. Muñoz, P. Titz, M. & Vogel, J. 2019	Scientific article	Static	CGE-MRIO	Policy changes	After changes	Emissions	Change in demand (and supply)	Austria, EU & RoW	Previous studies, economic theory, author choices, expert estimates & EMAS data, company data & case studies	Previous studies, GTAP 9, Eurostat, CDIAC, UNFCCC, regional SAMs, Statistik Austria	Environmental

APPENDIX B: TABLE OF CONSTRUCTED MODELS EXTENSION INDICATORS

Indicator	Emissions	per million of output	Reference
Carbon dioxide	CO_2	kilotons	Corsatea et al., 2019
Methane	CH_4	tonnes	Genty, 2012
Nitrous oxide	N_2O	tonnes	Genty, 2012
Nitrogen oxides	NOx	tonnes	Genty, 2012
Sulphur oxides	SOx	tonnes	Genty, 2012
Carbon monoxide	CO	tonnes	Genty, 2012
Non-methane volatile organic compounds	NMVOC	tonnes	Genty, 2012
Ammonia	NH_3	tonnes	Genty, 2012
	Energy use		
Coal coke crude		terajoules	Corsatea et al., 2019
Diesel		terajoules	Corsatea et al., 2019
Electr heatprod		terajoules	Corsatea et al., 2019
Fuel oil		terajoules	Corsatea et al., 2019
Gasoline		terajoules	Corsatea et al., 2019

Jet fuel		terajoules	Corsatea et al., 2019
Liquid (gaseous bio-fuels)		terajoules	Corsatea et al., 2019
Natural gas		terajoules	Corsatea et al., 2019
Other gas		terajoules	Corsatea et al., 2019
Other petrol		terajoules	Corsatea et al., 2019
Other sources		terajoules	Corsatea et al., 2019
Renewables nuclear		terajoules	Corsatea et al., 2019
Waste		terajoules	Corsatea et al., 2019
Total energy		terajoules	Corsatea et al., 2019
	Land use		
Arable area		1000 hectares	Genty, 2012
Permanent crops area		1000 hectares	Genty, 2012
Pastures area		1000 hectares	Genty, 2012
Forest area		1000 hectares	Genty, 2012
Total land use		1000 hectares	Genty, 2012
	Water use		

Blue water		1000 cubic meters	Genty, 2012
Green water		1000 cubic meters	Genty, 2012
Grey water		1000 cubic meters	Genty, 2012
Total water use		1000 cubic meters	Genty, 2012
	Material use		
Biomass animals used		1000 tonnes	Genty, 2012
Biomass feed used		1000 tonnes	Genty, 2012
Biomass food used		1000 tonnes	Genty, 2012
Biomass forestry used		1000 tonnes	Genty, 2012
Biomass other used		1000 tonnes	Genty, 2012
Biomass animals un-used		1000 tonnes	Genty, 2012
Biomass feed unused		1000 tonnes	Genty, 2012
Biomass food unused		1000 tonnes	Genty, 2012
Biomass forestry un-used		1000 tonnes	Genty, 2012
Biomass other un-used		1000 tonnes	Genty, 2012
Minerals construction used		1000 tonnes	Genty, 2012
Minerals industrial used		1000 tonnes	Genty, 2012
Minerals metals used		1000 tonnes	Genty, 2012

Minerals construction unused		1000 tonnes	Genty, 2012
Minerals industrial un-used		1000 tonnes	Genty, 2012
Minerals metals un-used		1000 tonnes	Genty, 2012
Total material use		1000 tonnes	Genty, 2012
Fossil coal used		1000 tonnes	Genty, 2012
Fossil gas used		1000 tonnes	Genty, 2012
Fossil oil used		1000 tonnes	Genty, 2012
Fossil other used		1000 tonnes	Genty, 2012
Fossil coil unused		1000 tonnes	Genty, 2012
Fossil gas unused		1000 tonnes	Genty, 2012
Fossil oil unused		1000 tonnes	Genty, 2012
Fossil other unused		1000 tonnes	Genty, 2012
	Social		
Hours	H	millions of hours	Timmer et al., 2015
Work years	EMP	millions of work years	Timmer et al., 2015
Compensation	COMP	millions of output unit	Timmer et al., 2015
Labour comp high-skilled	LABHS	millions of output unit	Timmer et al., 2015

Labour comp medium-skilled	LABMS	millions of output unit	Timmer et al., 2015
Labour comp low-skilled	LABLS	millions of output unit	Timmer et al., 2015
Hours low-skilled	H_HS	millions of hours	Timmer et al., 2015
Hours medium-skilled	H_MS	millions of hours	Timmer et al., 2015
Hours high-skilled	H_LS	millions of hours	Timmer et al., 2015

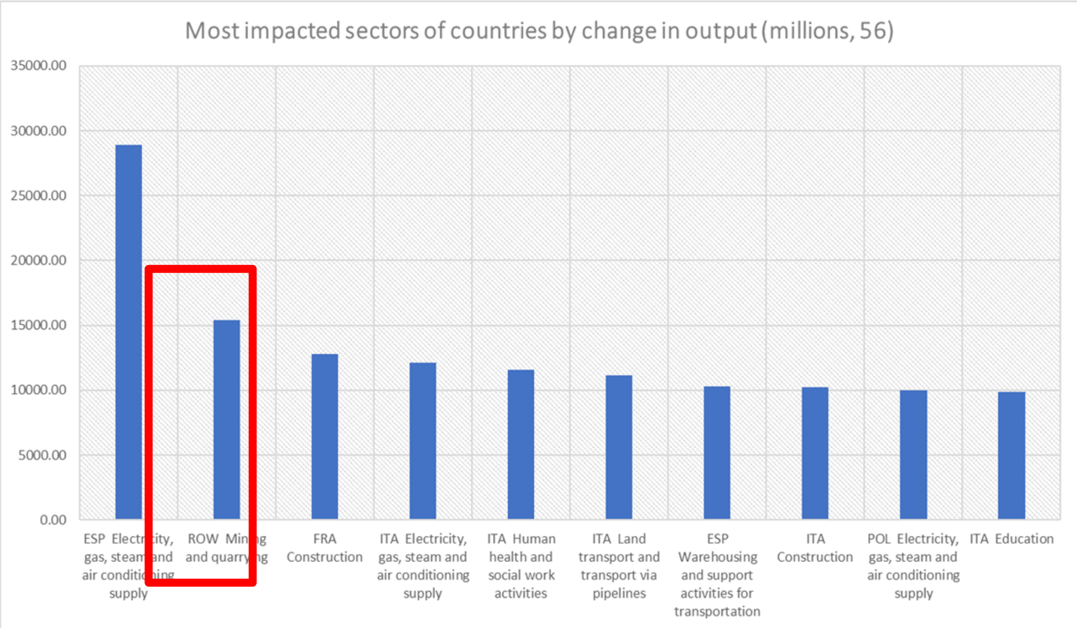
APPENDIX C: EU RECOVERY AND RESILIENCE FACILITY: MAXIMUM GRANT ALLOCATIONS AT CURRENT PRICES IN BILLION EUROS (BASED ON EUROPEAN COMISSION, 2021)

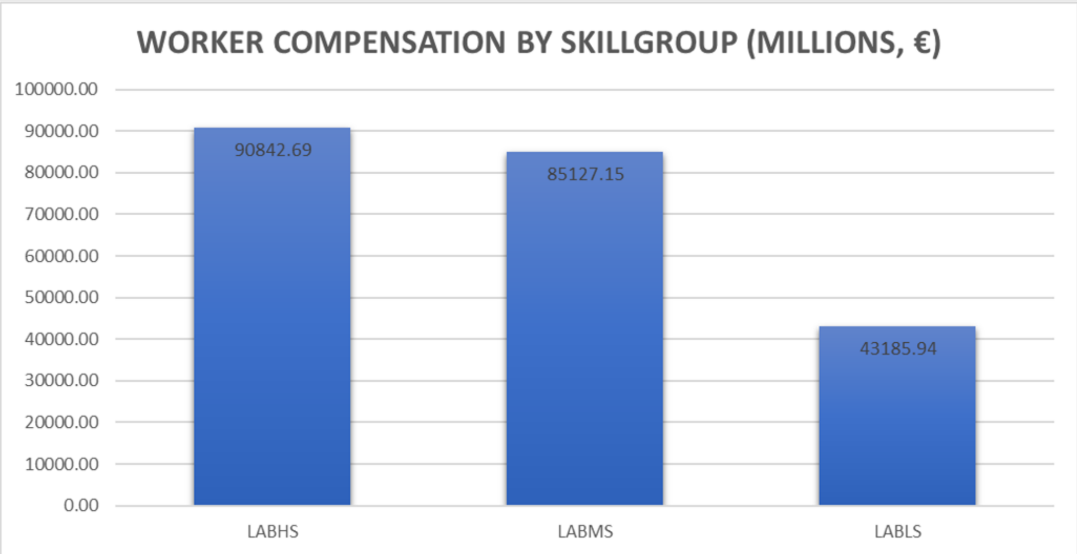
Country	First allocation (70 %)	Second allocation (30 %)	Total
Belgium	3.6	2.3	**5.9**
Bulgaria	4.6	1.6	**6.3**
Czechia	3.5	3.5	**7.1**
Denmark	1.3	0.2	**1.6**
Germany	16.3	9.3	**25.6**
Estonia	0.8	0.2	**1.0**
Ireland	0.9	0.1	**1.0**
Greece	13.5	4.3	**17.8**
Spain	46.6	22.9	**69.5**
France	24.3	15.0	**39.4**
Croatia	4.6	1.7	**6.3**
Italy	47.9	21.0	**68.9**
Cyprus	0.8	0.2	**1.0**
Latvia	1.6	0.3	**2.0**
Lithuania	2.1	0.1	**2.2**
Luxembourg	0.1	0.0	**0.1**
Hungary	4.6	2.5	**7.2**
Malta	0.2	0.1	**0.3**
Netherlands	3.9	2.0	**6.0**
Austria	2.2	1.2	**3.5**
Poland	20.3	3.6	**23.9**
Portugal	9.8	4.1	**13.9**
Romania	10.2	4.0	**14.2**
Slovenia	1.3	0.5	**1.8**
Slovakia	4.6	1.7	**6.3**
Finland	1.7	0.4	**2.1**
Sweden	2.9	0.4	**3.3**
EU 27	**234.5**	**103.5**	**338.0**

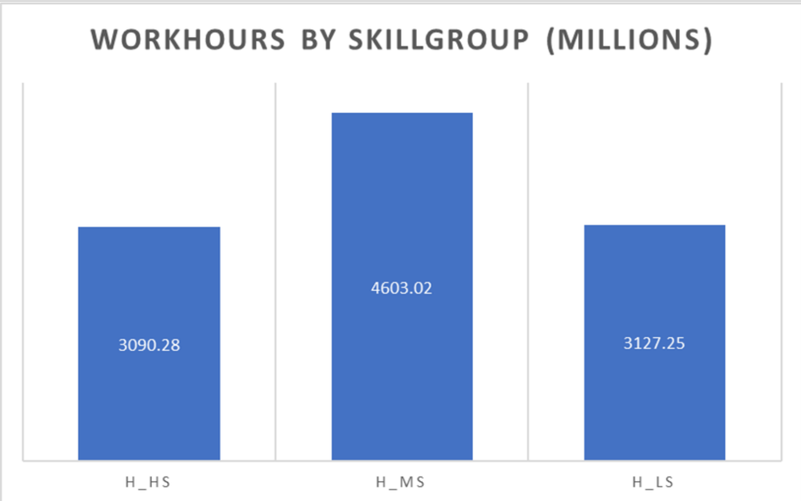
APPENDIX D: FINNISH DOWNSTREAM IMPACTS FROM FOREIGN EU RECOVERY AND RESILIENCE FACILITY GRANTS INVESTMENTS

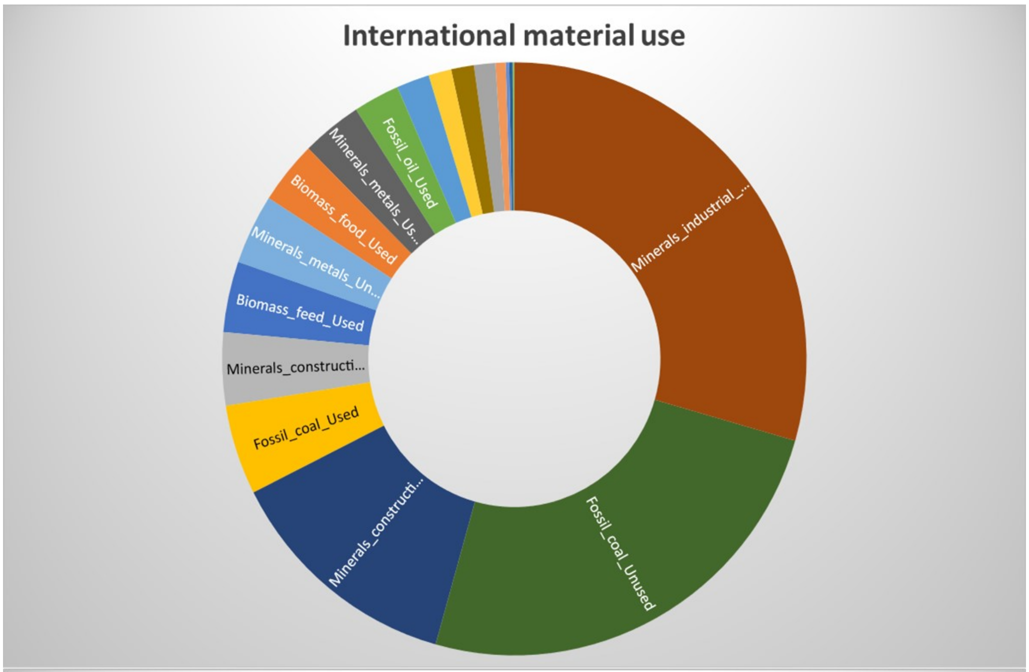
		TOTAL	AUT	BEL	BGR	CYP	CZE	DEU	DNK	ESP	EST	FIN	FRA	GRC	HRV	HUN	IRL	ITA	LTU	LUX	LVA	MLT	NLD	POL	PRT	ROU	SVK	SVN	SWE
m. €	**Change in output total**	1869.141	22.2861	51.68307	28.93834	5.18991	36.7801	178.0865	38.80825	212.0328	113.5274	[redacted]	185.7981	51.77405	28.11645	31.53097	5.40413	216.8512	38.27573	0.57351	93.15686	1.565135	59.51111	164.4409	43.27939	45.9694	23.53268	7.322156	184.707
	of which due to direct final demand	323.637	4.689513	4.575988	3.104816	0.388231	4.355983	48.55194	14.51304	13.42566	25.10386	[redacted]	32.32834	0.938583	3.630766	3.600869	1.224565	24.37697	2.575225	0.041531	14.14482	0.067009	6.783843	13.31845	1.688456	3.025821	0.786197	1.163969	95.23252
	of which due to intermediate demand	1545.504	17.59659	47.10708	25.83352	4.801679	32.42412	129.5345	24.29522	198.6072	88.42356	[redacted]	153.4698	50.83547	24.48569	27.9301	4.179565	192.4742	35.7005	0.531979	79.01204	1.498127	52.72726	151.1224	41.59093	42.94358	22.74648	6.158188	89.47445
m. €	**Value added**	707.4779	8.945164	19.9848	10.81808	2.055099	13.83567	68.58252	14.40359	81.00617	43.28746	[redacted]	70.05023	19.64329	10.57129	12.13009	2.110988	83.82056	14.29443	0.232201	33.19324	0.612266	22.24116	62.01987	16.05741	16.89852	8.809349	2.840995	69.0335
m. €	**GDP**	746.3183	9.367706	20.98317	11.36154	2.167431	14.54044	72.39375	15.34476	85.12167	46.09825	[redacted]	73.575	20.92122	11.08092	12.72659	2.258627	88.26021	15.22607	0.245127	35.37889	0.642696	23.35498	65.18871	16.8678	17.71087	9.235362	2.982251	73.28432
	Rise in GDP	0.003142	3.94E-05	8.84E-05	4.78E-05	9.13E-06	6.12E-05	0.000305	6.46E-05	0.000358	0.000194	[redacted]	0.00031	8.81E-05	4.67E-05	5.36E-05	9.51E-06	0.000372	6.41E-05	1.03E-06	0.000149	2.71E-06	9.83E-05	0.000274	7.1E-05	7.46E-05	3.89E-05	1.26E-05	0.000309
10 yrs	**Employees (10 years)**	797.9093	10.18067	22.25463	11.86611	2.489367	15.39073	80.60108	16.43907	90.30505	52.52071	[redacted]	78.99267	22.54329	11.85077	13.57737	2.435919	94.86452	16.15367	0.271892	34.40217	0.700164	25.61946	68.58196	17.53454	18.25462	9.747194	3.291746	77.03994
m. €	**Taxes**	239.0998	2.999923	6.794445	3.686866	0.69759	4.693206	22.65719	4.947565	27.41174	14.7011	[redacted]	23.60165	6.632882	3.645278	4.087806	0.689381	28.55428	4.819929	0.077256	11.11412	0.209054	7.603115	21.03493	5.487165	5.778192	3.004935	0.951253	23.21896
	Local income tax	69.1483	0.899428	1.966718	1.048145	0.207346	1.349199	6.99809	1.382793	7.86716	4.270121	[redacted]	6.927756	1.856143	1.050596	1.18078	0.201772	8.20911	1.365271	0.023238	3.021773	0.061956	2.219576	6.012525	1.542046	1.623023	0.85442	0.285497	6.723813
	VAT	143.944	1.793274	4.112611	2.238267	0.417266	2.832878	13.27167	3.012777	16.5502	8.816671	[redacted]	14.14132	4.001889	2.209948	2.466422	0.411012	17.26647	2.923285	0.04582	6.750366	0.126454	4.590571	12.73678	3.337495	3.521887	1.823984	0.566035	13.97869
	Corporation tax	20.73796	0.239782	0.566176	0.320394	0.057731	0.408504	1.865934	0.445718	2.39255	1.282484	[redacted]	2.020959	0.627769	0.308381	0.351355	0.060434	2.45059	0.422132	0.006536	1.100294	0.016198	0.628754	1.824041	0.490422	0.508643	0.261074	0.078699	2.002412
	Real estate tax	5.269512	0.067439	0.148939	0.08006	0.015247	0.102625	0.5215	0.106277	0.601827	0.331827	[redacted]	0.511624	0.14708	0.076353	0.089249	0.016163	0.628109	0.10924	0.001662	0.241684	0.004446	0.164214	0.461581	0.117202	0.12464	0.065458	0.021022	0.514045
		0																											
TJ	**Energy use**	1781.647	20.34451	48.69258	31.45786	4.196497	37.36792	158.1382	27.48573	258.7226	78.06387	[redacted]	162.3993	55.32842	26.88276	32.48957	4.691889	236.0328	34.00748	0.477641	78.04349	1.369963	44.22832	182.5789	44.2315	51.77961	25.93618	6.77353	129.9261
	Coal (coke crude)	144.6231	1.863766	4.317077	2.291466	0.332648	3.106586	11.94097	2.371797	18.54439	8.34006	[redacted]	12.4426	4.171191	2.050132	2.572266	0.364525	17.63448	3.527307	0.038848	8.727157	0.106952	3.746133	14.30956	3.369995	3.753007	1.900193	0.547891	12.25212
	Diesel	47.12934	0.58562	1.175872	0.668299	0.126331	0.929255	5.256363	0.740024	6.108441	2.717529	[redacted]	4.736373	1.226788	0.601861	0.905716	0.116881	5.353584	0.921722	0.013038	2.32723	0.035405	1.377829	4.433814	0.988831	1.061395	0.573009	0.280477	3.867648
	Electronic heatproduction	438.7843	4.582255	11.50311	8.251854	1.070869	9.388635	36.73283	7.410937	65.41406	18.08289	[redacted]	41.04374	14.08774	7.174014	8.038719	1.212152	59.97631	7.339013	0.118748	14.78778	0.349334	11.9707	45.78466	11.72013	13.75908	6.822368	1.686783	30.47557
	Fuel (oil)	83.30892	0.829427	1.818288	1.14117	0.202435	1.329075	17.15632	1.381978	8.249296	4.370266	[redacted]	9.728231	2.104968	0.972141	1.161112	0.192824	8.005629	1.359556	0.019712	2.897853	0.053525	2.937539	6.344127	1.601958	1.807113	0.886206	0.301383	6.456797
	Gasoline	7.631541	0.081393	0.206868	0.095026	0.021101	0.12034	0.94776	0.158648	0.716277	0.458175	[redacted]	0.765645	0.16806	0.086824	0.115422	0.02266	0.733592	0.174727	0.00235	0.647387	0.005673	0.235571	0.562653	0.146949	0.147209	0.075262	0.027737	0.908231
	Jetfuel	29.726	0.878995	1.079168	0.246899	0.067292	0.537885	1.794232	0.298339	2.392564	1.066016	[redacted]	3.286303	0.379952	0.191199	0.681761	0.091244	4.045998	0.571082	0.012057	1.730107	0.024502	0.77332	2.887376	0.552723	0.322562	0.178178	0.11311	5.523137
	Liquid gaseous biofuels	16.23582	0.18864	0.440175	0.212769	0.041601	0.289447	1.690087	0.29854	1.820502	0.975695	[redacted]	1.552752	0.378825	0.190835	0.277151	0.043141	1.687265	0.377275	0.004528	1.300435	0.011731	0.469073	1.366913	0.321657	0.337256	0.179693	0.079426	1.700408
	Natural gas	135.9127	1.430181	3.871391	2.219661	0.309865	2.645985	11.32168	2.301496	18.20587	6.542949	[redacted]	11.80255	3.78725	1.877706	2.316417	0.36754	16.55249	3.0845	0.036407	9.842485	0.101021	3.21225	12.87549	3.119983	3.637639	1.805551	0.47454	12.16976
	Other gas	13.98466	0.167473	0.399086	0.243526	0.026249	0.347061	1.139604	0.298803	1.523681	0.625644	[redacted]	1.407484	0.351111	0.245292	0.240598	0.027527	1.782349	0.249921	0.003485	0.486142	0.010012	0.812361	1.384919	0.397897	0.475459	0.209099	0.065856	1.06402
	Other petrol	72.10301	0.519089	2.158778	0.825365	0.154517	1.004131	6.201526	1.88866	5.59037	4.312634	[redacted]	6.409214	1.20347	0.727039	0.939413	0.231447	5.67101	2.081779	0.019454	10.39369	0.046239	2.084197	4.814713	1.427216	1.360743	0.643512	0.21131	11.1835
	Other sources	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Renewables, nuclear	775.377	8.987934	21.20327	14.96112	1.804954	17.29394	62.57038	10.08117	127.7429	29.82263	[redacted]	67.74929	26.94944	12.50193	14.93061	1.980074	112.2608	13.99607	0.204549	24.27198	0.612855	16.17256	86.03446	20.15571	24.62136	12.40327	2.916976	43.14677
	Waste	16.83087	0.229733	0.519494	0.300699	0.038633	0.375586	1.386444	0.255334	2.414197	0.74938	[redacted]	1.475088	0.519622	0.263795	0.310392	0.041874	2.329313	0.324534	0.004465	0.631244	0.012715	0.43678	1.780247	0.428459	0.496794	0.259843	0.068041	1.178163
		0																											
1000ha	**Land use total**	143.9779	1.282936	3.688959	2.201518	0.470846	2.55708	10.35666	4.576378	18.66201	10.83785	[redacted]	13.132	8.529278	1.848531	2.219616	0.589103	18.90644	3.145141	0.036739	3.867273	0.103253	4.08309	12.41251	3.538284	3.339256	1.990127	0.438966	11.16408
	Arable area	13.60024	0.121187	0.348461	0.207957	0.044476	0.241543	0.978297	0.432287	1.762825	1.02375	[redacted]	1.240456	0.805681	0.174613	0.209666	0.055647	1.785913	0.297092	0.00347	0.365305	0.009753	0.385691	1.172493	0.334228	0.315428	0.187989	0.041465	1.054565
	Permanent crops area	0.030129	0.000268	0.000772	0.000461	9.85E-05	0.000535	0.002167	0.000958	0.003905	0.002268	[redacted]	0.002748	0.001785	0.000387	0.000464	0.000123	0.003956	0.000658	7.69E-06	0.000809	2.16E-05	0.000854	0.002597	0.00074	0.000699	0.000416	9.19E-05	0.002336
	Pastures area	0.204877	0.001826	0.005249	0.003133	0.00067	0.003639	0.014737	0.006512	0.026556	0.015422	[redacted]	0.018687	0.012137	0.00263	0.003158	0.000838	0.026903	0.004475	5.23E-05	0.005503	0.000147	0.00581	0.017663	0.005035	0.004752	0.002832	0.000625	0.015886
	Forest area	130.1427	1.159655	3.334477	1.989968	0.425601	2.311363	9.361461	4.13662	16.86872	9.796412	[redacted]	11.87011	7.709676	1.6709	2.006326	0.532494	17.08966	2.842915	0.033209	3.495656	0.093331	3.690735	11.21975	3.19828	3.018377	1.79889	0.396784	10.09129
		0																											
1000m^3	**Water use total**	67785.46	812.4863	1838.445	1067.716	195.9982	1328.205	5241.343	1733.092	8577.242	4425.797	[redacted]	6102.301	3129.011	946.448	1107.868	230.7762	8958.925	1456.934	17.74064	2266.881	49.02049	2050.188	6234.696	1669.231	1690.097	969.9485	241.7125	5443.357
	Blue	25227.11	430.5315	751.8667	402.1866	60.19282	552.9982	2162.685	424.2606	2988.731	1342.319	[redacted]	2220.583	700.5433	380.2119	439.7226	59.93694	3354.521	545.0673	6.868684	1120.401	18.31845	859.3926	2483.008	608.3792	670.9129	373.8548	109.361	2160.253
	Green	38229.51	340.6497	979.5051	584.5546	125.0207	678.9646	2749.936	1215.135	4955.201	2877.704	[redacted]	3486.853	2264.723	490.8282	589.3599	156.4206	5020.102	835.1086	9.755031	1026.852	27.41616	1084.156	3295.811	939.4973	886.6507	528.4252	116.5557	2964.324
	Grey	4328.843	41.30516	107.0733	80.97504	10.78471	96.24206	328.722	93.69563	633.3101	205.7737	[redacted]	394.8653	163.7447	75.40802	78.78523	14.41862	584.3022	76.75783	1.116924	119.6287	3.285881	106.639	455.8774	121.354	132.5329	67.66845	15.79583	318.7803
		0																											
	Total material use	2129.009	13.91414	49.74815	26.23354	4.400971	30.83028	143.5967	34.95691	168.3909	453.6889	[redacted]	154.1205	47.13701	18.58019	26.05629	4.124236	157.2384	66.41605	0.462664	258.2848	1.326287	57.04079	150.2494	38.80326	36.12946	21.37914	5.56903	160.3315
		0																											
1000t	**Biomass total**	265.3077	2.364063	6.797634	4.05673	0.867627	4.711923	19.08419	8.432877	34.38843	19.97088	[redacted]	24.19829	15.71687	3.406281	4.090079	1.085538	34.83883	5.795541	0.067699	7.126212	0.190264	7.523898	22.87249	6.519985	6.153236	3.6672	0.808881	20.57201
	Biomass animals	1.186876	0.010576	0.03041	0.018148	0.003881	0.021079	0.085375	0.037725	0.15384	0.089341	[redacted]	0.108253	0.070311	0.015238	0.018297	0.004856	0.155854	0.025927	0.000303	0.03188	0.000851	0.033659	0.102322	0.029168	0.027527	0.016406	0.003619	0.092031
	Biomass feed	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Biomass food	46.2535	0.412149	1.185093	0.707247	0.151261	0.821472	3.32712	1.47018	5.995248	3.481705	[redacted]	4.218708	2.740066	0.593848	0.713061	0.189252	6.073771	1.010389	0.011803	1.242377	0.033171	1.31171	3.987569	1.136688	1.07275	0.639336	0.14102	3.586506
	Biomass forestry	217.8673	1.941338	5.582131	3.331335	0.712484	3.869371	15.67169	6.924971	28.23934	16.39983	[redacted]	19.87133	12.9065	2.797195	3.358721	0.89143	28.60921	4.759225	0.055593	5.851954	0.156243	6.178529	18.7826	5.354129	5.05296	3.011458	0.664242	16.89347
	Biomass other	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0																											
1000t	**Fossil fuels total**	82.56977	0.511717	1.902887	0.982525	0.156542	1.157152	5.516422	1.175125	5.936869	19.21552	[redacted]	5.756098	1.392043	0.672267	0.973195	0.134627	5.42281	2.685741	0.017499	11.12737	0.050331	2.193805	5.643326	1.430284	1.328072	0.784713	0.210894	6.191929
	Fossil coal	82.56977	0.511717	1.902887	0.982525	0.156542	1.157152	5.516422	1.175125	5.936869	19.21552	[redacted]	5.756098	1.392043	0.672267	0.973195	0.134627	5.42281	2.685741	0.017499	11.12737	0.050331	2.193805	5.643326	1.430284	1.328072	0.784713	0.210894	6.191929
	Fossil gas	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fossil oil	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fossil other	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0																											
1000t	**Minerals total**	1781.132	11.03836	41.04763	21.19429	3.376802	24.96121	118.996	25.34891	128.0656	414.5025	[redacted]	124.1662	30.02809	14.50164	20.99302	2.904071	116.9767	57.93476	0.377467	240.0312	1.085692	47.32309	121.7335	30.85299	28.64815	16.92723	4.549255	133.5676
	Minerals construction	204.2192	1.265625	4.706396	2.430072	0.387174	2.861976	13.64372	2.906429	14.68361	47.52559	[redacted]	14.23651	3.44293	1.662714	2.406996	0.332972	13.41219	6.642623	0.043279	27.52125	0.124482	5.425921	13.9576	3.53751	3.284709	1.940825	0.521604	15.31445
	Minerals industrial	1515.144	9.389929	34.91771	18.0292	2.872522	21.23358	101.2256	21.56339	108.9407	352.602	[redacted]	105.6236	25.5438	12.33601	17.85799	2.470386	99.50781	49.28297	0.321097	204.1858	0.923559	40.25601	103.5542	26.24551	24.36993	14.39937	3.869884	113.621
	Minerals metals	61.76932	0.382808	1.423524	0.735014	0.117107	0.86565	4.12676	0.879095	4.441291	14.37487	[redacted]	4.306058	1.041368	0.502914	0.728034	0.100713	4.05673	2.009166	0.01309	8.324237	0.037652	1.641156	4.221696	1.069976	0.993512	0.587033	0.157767	4.632098
		0																											
kt	**CO2**	289.3186	3.640173	8.681076	4.123442	0.647525	5.61351	31.00292	5.193951	31.67983	15.74376	[redacted]	28.16958	7.130438	3.651497	4.869238	0.731444	32.48685	6.192063	0.077981	17.90237	0.202993	9.338225	25.96141	6.390291	6.814889	3.375898	1.158911	28.53836
t	CH4	792.2556	7.688327	20.88283	11.62435	2.467342	13.91167	64.63515	22.96111	95.96003	56.71048	[redacted]	73.58373	38.95298	10.12561	12.21716	3.015456	98.08023	17.36957	0.214267	32.16848	0.581826	22.95771	66.21117	18.29995	17.67361	10.19874	2.600138	71.16373
t	N2O	128.8679	1.262674	3.237168	2.010097	0.358663	2.612118	9.758541	3.686701	15.52057	8.531645	[redacted]	11.74098	5.730395	1.951858	2.154672	0.506182	15.637	2.7357	0.033129	4.821598	0.089823	3.395003	12.04845	3.42945	3.13675	1.749263	0.439844	12.28961
t	NOX	1499.175	18.48159	36.7599	18.68056	3.354714	23.30116	288.3438	22.80634	140.9908	74.15931	[redacted]	172.0663	33.3848	15.61314	21.73064	3.377002	143.6032	26.72289	0.362154	74.85975	0.934721	48.83215	114.0944	27.15544	29.00372	14.80581	5.615566	140.1354
t	SOX	738.9329	8.181865	18.4537	9.702083	1.597218	12.21147	134.0596	13.15913	66.44553	38.06315	[redacted]	82.06127	15.76092	8.904072	10.17165	1.690664	68.63816	14.0619	0.172672	42.11735	0.452248	25.87434	55.8102	14.42424	15.65919	7.825374	2.650888	70.78403
t	CO	1283.216	16.29734	35.73073	17.61517	3.189566	22.9544	120.3316	24.38325	138.8024	82.97633	[redacted]	122.4107	34.57934	15.64487	21.34731	3.658123	144.0509	28.35224	0.364227	90.96902	0.93474	36.68671	109.3198	27.54557	27.8159	14.71648	4.67125	137.8681
t	NMVOC	360.5781	4.520273	9.929441	5.745122	0.877762	7.432269	33.56431	6.747106	44.71837	18.78728	[redacted]	33.30421	10.31783	5.324955	6.370278	1.059783	44.06715	7.277264	0.096961	18.11643	0.263013	9.427751	34.80255	8.788017	9.266527	4.888772	1.414469	33.47025
t	NH3	201.1323	1.799312	5.151954	3.089025	0.650462	3.614907	14.51634	6.351471	25.92955	15.00625	[redacted]	18.42702	11.7099	2.629535	3.111942	0.813824	26.30843	4.368082	0.051295	5.443934	0.144335	5.807949	17.40631	4.973901	4.715395	2.785911	0.621353	15.70387
		0																											
year	**Total employees**	7979.093	101.8067	222.5463	118.6611	24.89367	153.9073	806.0108	164.3907	903.0505	525.2071	[redacted]	789.9267	225.4329	118.5077	135.7737	24.35919	948.6452	161.5367	2.718915	344.0217	7.001644	256.1946	685.8196	175.3454	182.5462	97.47194	32.91746	770.3994
h	**Total hours**	9023651	115823.8	253487.5	136135.2	28766.91	177128.9	921871.2	181341	1030984	572008.6	[redacted]	908435.2	251537.6	136649.1	157952.4	26670.95	1081957	174861.3	3148.671	358796.5	7999.865	296358.3	783471.3	200475.8	210361.3	111047.5	37292.49	859089.4
	Low-skilled	1558974	19262.61	42693.6	23446.72	4714.428	30571.96	160595.6	31321.08	178915.4	102691.6	[redacted]	157080.6	44287.48	23217.36	27097.66	4291.275	182847.8	30929.61	497.6105	65676.72	1323.42	49913.96	136029.5	34714.57	36525.23	19227.63	6551.608	144548.8
	Medium-skilled	4332882	54337.77	120343.4	65735.25	13328.91	85643.35	440810.9	87711.16	496596.6	278585.4	[redacted]	437527.8	122006.7	65898.81	75505.53	12165.97	512980.7	85198.04	1428.415	175580	3754.989	140480.4	378645.1	97131.12	102269.9	53714.28	18063.27	407438.6
	High-skilled	3131795	42223.43	90450.51	46953.22	10723.58	60913.63	320464.7	62308.73	355471.7	190731.5	[redacted]	313826.7	85243.39	47532.91	55349.19	10213.7	386128.1	58733.64	1222.645	117539.7	2921.457	105963.9	268796.7	68630.11	71566.15	38105.62	12677.62	307102
m. €	**Total compensation**	362.3787	4.729958	10.26511	5.536274	1.118358	7.149269	36.95364	7.205844	41.40163	22.36971	[redacted]	36.44698	9.856967	5.563376	6.310491	1.072399	43.62149	6.949569	0.124896	14.35582	0.327417	11.76616	31.69777	8.105111	8.560389	4.487527	1.481875	34.92071
	Low-skilled	53.67436	0.670772	1.47552	0.81772	0.155627	1.058915	5.548223	1.058033	6.15569	3.452068	[redacted]	5.428127	1.470827	0.810141	0.929828	0.143899	6.280785	1.055999	0.016667	2.285348	0.045979	1.698379	4.71875	1.204895	1.278561	0.665608	0.223356	5.024639
	Medium-skilled	147.3614	1.858788	4.099771	2.270927	0.433834	2.934785	14.94655	2.950684	16.91166	9.277538	[redacted]	14.90489	4.037968	2.275986	2.556191	0.402726	17.41024	2.884939	0.047009	6.018509	0.128818	4.705565	13.00131	3.33842	3.545575	1.841812	0.608507	13.9684
	High-skilled	161.343	2.200397	4.689816	2.447627	0.528898	3.155569	16.45886	3.197127	18.33428	9.640102	[redacted]	16.11396	4.348171	2.477248	2.824472	0.525775	19.93047	3.008631	0.06122	6.051965	0.15262	5.362219	13.9777	3.561796	3.736253	1.980107	0.650012	15.92767

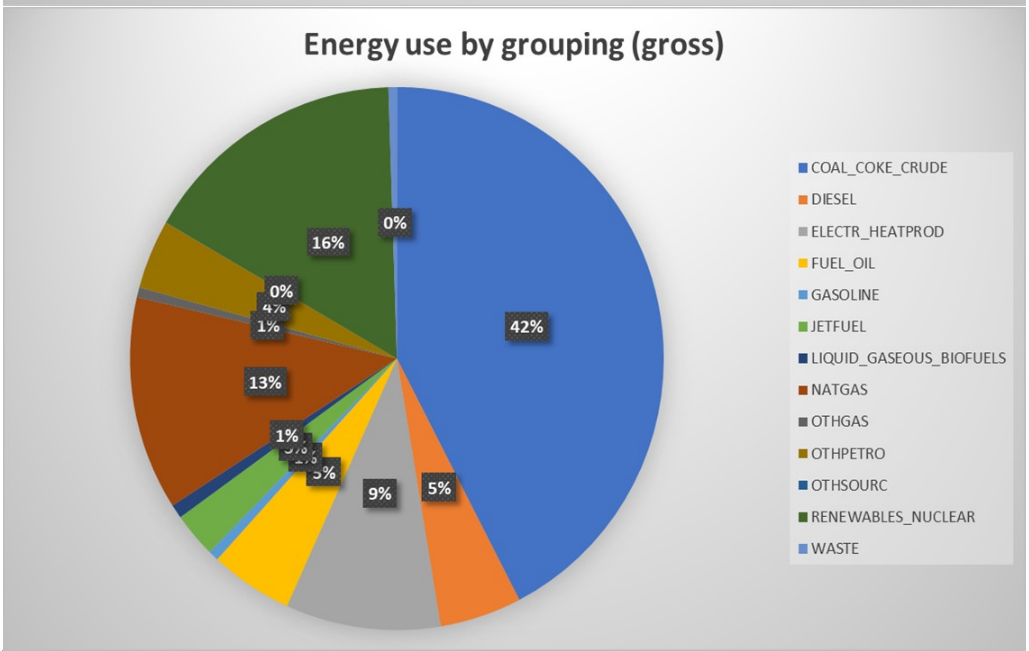
APPENDIX E: GLOBAL IMPACTS DASHBOARD OF THE FACILITY SIMULATION

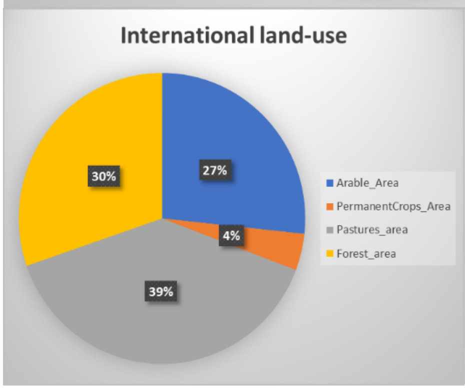


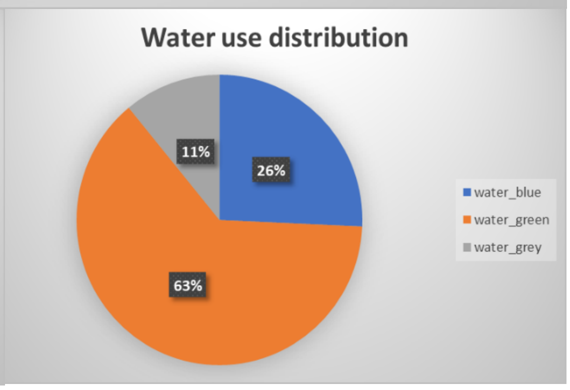





International material use
Minerals_industrial_...
Fossil_coal_Unused
Minerals_constructi...
Fossil_coal_Used
Minerals_constructi...
Biomass_feed_Used
Minerals_metals_Un...
Biomass_food_Used
Minerals_metals_Us...
Fossil_oil_Used


Energy use by grouping (gross)
42%
5%
9%
5%
1%
13%
1%
0%
16%
0%
COAL_COKE_CRUDE
DIESEL
ELECTR_HEATPROD
FUEL_OIL
GASOLINE
JETFUEL
LIQUID_GASEOUS_BIOFUELS
NATGAS
OTHGAS
OTHPETRO
OTHSOURC
RENEWABLES_NUCLEAR
WASTE


International land-use
27%
4%
39%
30%
Arable_Area
PermanentCrops_Area
Pastures_area
Forest_area


Water use distribution
26%
63%
11%
water_blue
water_green
water_grey

APPENDIX F: DISTRIBUTION OF FINNISH IMPACTS BY MAJOR REGION

	SA5 Åland	SA2 Southern Finlan	SA1 Helsinki-Uusima	SA3 Western Finlanc	SA4 Northern and Ea
01 Crop and animal pro	0.8%	6.6%	5.2%	60.9%	26.6%
02_03 Forestry and fish	1.4%	20.3%	22.0%	7.6%	48.8%
05_09 Mining and quar	0.0%	2.2%	0.6%	1.5%	95.7%
10 Manufacture of foo	0.5%	27.2%	18.1%	43.7%	10.5%
11_12 Manufacture of	0.1%	50.3%	30.8%	8.0%	10.9%
13_15 Manufacture of	0.1%	9.4%	3.3%	64.0%	23.2%
16 Manufacture of woo	0.3%	14.3%	0.2%	28.4%	56.8%
17 Manufacture of pap	0.0%	36.7%	12.7%	35.0%	15.6%
18 Printing and reprodu	1.4%	14.3%	59.9%	9.0%	15.5%
19_21 Manufacture of	0.0%	22.0%	74.2%	0.9%	2.8%
22 Manufacture of rubl	0.8%	18.3%	3.6%	69.5%	7.9%
23 Manufacture of oth	0.2%	31.7%	42.7%	3.8%	21.7%
24 Manufacture of basi	0.0%	1.5%	12.2%	22.4%	63.9%
25 Manufacture of fabr	0.4%	9.3%	2.5%	55.9%	31.8%
26 Manufacture of com	0.1%	2.4%	64.9%	7.5%	25.1%
27 Manufacture of elec	0.0%	7.8%	61.1%	26.6%	4.5%
28 Manufacture of mac	0.0%	21.3%	26.1%	44.4%	8.1%
29_30 Manufacture of	0.0%	57.2%	3.0%	29.1%	10.8%
31_32 Other manufactu	0.0%	37.6%	22.2%	23.4%	16.7%
33 Koneiden ja laitteid	0.3%	15.8%	18.3%	54.8%	10.8%
35 Electricity, gas, stea	0.3%	10.6%	55.1%	21.7%	12.4%
36_39 Water supply; se	0.2%	58.6%	12.4%	2.6%	26.1%
41+432_439 Constructio	0.7%	8.9%	42.0%	25.9%	22.6%
42+431 Water and land	0.3%	15.6%	31.8%	23.7%	28.4%
45 Wholesale and reta	0.2%	16.3%	50.0%	19.1%	14.5%
46 Wholesale trade, ex	0.2%	4.5%	89.7%	4.3%	1.4%
47 Retail trade, except	0.3%	21.3%	36.8%	23.2%	18.4%
491_492 Rail transport	0.0%	24.6%	50.1%	16.1%	9.1%
4931+4393 Urban, subu	0.1%	16.0%	55.4%	17.0%	11.4%
4932 Taxi operation	0.5%	3.0%	69.1%	17.8%	9.7%
494 Freight transport b	0.6%	16.8%	37.1%	23.1%	22.4%
50 Water transport	12.3%	10.4%	76.1%	1.0%	0.2%
51 Air transport	0.1%	0.0%	99.8%	0.1%	0.0%
52_53 Warehousing an	3.0%	15.3%	58.5%	16.3%	6.9%
55 Accommodation	0.7%	12.9%	44.6%	19.2%	22.6%
56 Food and beverage	0.2%	19.5%	47.6%	19.8%	13.0%
58 Publishing activities	0.1%	1.8%	93.2%	2.8%	2.1%
59_60 Motion picture,	0.1%	0.9%	95.4%	2.3%	1.3%
61 Telecommunication	0.3%	3.5%	76.1%	15.0%	5.0%
62_63 Computer progra	0.4%	3.6%	84.4%	5.9%	5.6%
64 Financial service act	0.5%	3.7%	88.3%	3.5%	4.0%
65_66 Insurance, reinsu	0.6%	4.9%	86.9%	5.4%	2.2%
681+68209+683 Other r	0.5%	16.1%	52.8%	18.1%	12.6%
68201_68202 Renting a	0.5%	20.2%	35.0%	23.3%	21.1%
69 Legal and accountin	1.5%	4.0%	80.8%	5.8%	7.8%
70 Activities of head of	0.1%	4.4%	88.1%	5.2%	2.2%
71 Architectural and er	0.3%	12.0%	59.3%	22.3%	6.0%
72 Scientific research a	0.1%	13.9%	50.0%	10.4%	25.6%
73 Advertising and mar	0.1%	3.9%	91.6%	2.9%	1.6%
74 Other professional,	0.1%	7.2%	74.9%	13.6%	4.2%
75 Veterinary activities	0.0%	24.5%	33.0%	24.7%	17.8%
77 Rental and leasing a	0.4%	3.2%	89.5%	5.8%	1.1%
78 Employment activiti	0.0%	10.5%	62.5%	17.0%	9.9%
79 Travel agency, tour	0.2%	4.5%	76.9%	6.5%	11.8%
80 Security and investi	0.3%	14.2%	39.2%	28.9%	17.4%
81 Services to building	0.3%	10.1%	59.6%	23.1%	6.9%
82 Office administrativ	0.1%	16.2%	71.3%	8.2%	4.2%
84 Public administratio	0.2%	19.8%	46.3%	18.5%	15.2%
85 Education	0.2%	18.8%	40.0%	24.0%	16.9%
86 Human health activi	0.3%	21.7%	34.6%	25.2%	18.3%
87_88 Residential care	0.3%	22.4%	35.3%	23.4%	18.7%
90_92 Arts, entertainm	0.2%	13.1%	60.5%	16.7%	9.5%
93 Sports activities and	0.4%	17.8%	42.0%	23.4%	16.5%
94 Activities of membe	0.4%	14.4%	54.0%	16.9%	14.2%
95 Repair of computers	0.1%	12.4%	57.3%	19.7%	10.5%
96 Other personal serv	0.4%	23.6%	37.5%	21.9%	16.7%
97_98 Activities of hou	0.0%	1.4%	93.2%	2.3%	3.1%

APPENDIX G: ALTERNATIVE INTERNATIONAL GRANT ALLOCATION SCHEMES RESULTS

	Scenario 1		Scenario 2		Scenario 3		Baseline	
Finnish downstream impacts	Results	Change	Results	Change	Results	Change	Results	
Change in output total	4681	150%	2406	29%	4636	148%	1869	**m. €**
of which due to direct final demand	1079	233%	560	73%	921	185%	324	
of which due to intermediate demand	3602	133%	1846	19%	3716	140%	1546	
Value added	1753	148%	907	28%	1730	145%	707	**m. €**
GDP	1860	149%	958	28%	1837	146%	746	**m. €**
Rise in GDP	0	149%	0	28%	0	146%	0	
Employees (10 years)	2007	152%	1028	29%	1982	148%	798	**10 yrs**
Taxes	592	148%	306	28%	585	144%	239	**m. €**
Local income tax	170	146%	89	29%	167	142%	69	
VAT	357	148%	183	27%	352	145%	144	
Corporation tax	52	150%	26	26%	52	149%	21	
Real estate tax	13	151%	7	29%	13	148%	5	
Energy use total gross	3732	109%	2140	20%	3756	111%	1782	**TJ**
Coal (coke crude)	354	145%	177	22%	362	150%	145	
Diesel	111	135%	60	27%	111	137%	47	
Electronic heatproduction	877	100%	523	19%	872	99%	439	
Fuel (oil)	178	113%	120	44%	173	108%	83	
Gasoline	21	176%	10	37%	21	175%	8	
Jetfuel	74	149%	41	38%	67	125%	30	
Liquid gaseous biofuels	43	167%	21	30%	44	170%	16	
Natural gas	325	139%	166	22%	332	144%	136	
Other gas	30	117%	18	27%	30	111%	14	
Other petrol	236	228%	98	36%	240	233%	72	
Other sources	0		0		0		0	
Renewables, nuclear	1448	87%	887	14%	1470	90%	775	
Waste	35	107%	20	19%	35	108%	17	
							0	
Land use total	366	154%	174	21%	362	152%	144	**1000ha**
Arable area	35	154%	16	21%	34	152%	14	
Permanent crops area	0	154%	0	21%	0	152%	0	
Pastures area	1	154%	0	21%	1	152%	0	
Forest area	331	154%	158	21%	328	152%	130	
							0	
Water use total	164839	143%	82896	22%	163482	141%	67785	**1000m^3**
Blue	58585	132%	31442	25%	58319	131%	25227	
Green	97188	154%	46303	21%	96207	152%	38230	
Grey	9066	109%	5151	19%	8955	107%	4329	
							0	
Total material use	9911	366%	2551	20%	11077	420%	2129	
							0	
Biomass total	674	154%	321	21%	668	152%	265	**1000t**
Biomass animals	3	154%	1	21%	3	152%	1	
Biomass feed	0		0		0		0	
Biomass food	118	154%	56	21%	116	152%	46	
Biomass forestry	554	154%	264	21%	548	152%	218	
Biomass other	0		0		0		0	
Fossil fuels total	409	396%	99	20%	461	459%	83	**1000t**
Fossil coal	409	396%	99	20%	461	459%	83	
Fossil gas	0		0		0		0	
Fossil oil	0		0		0		0	
Fossil other	0		0		0		0	
Minerals total	8827	396%	2131	20%	9948	459%	1781	**1000t**
Minerals construction	1012	396%	244	20%	1141	459%	204	
Minerals industrial	7509	396%	1813	20%	8463	459%	1515	
Minerals metals	306	396%	74	20%	345	459%	62	
CO2	712	146%	377	30%	710	145%	289	**kt**
CH4	2061	160%	989	25%	2041	158%	792	**t**
N2O	326	153%	161	25%	321	149%	129	**t**
NOX	3354	124%	2155	44%	3268	118%	1499	**t**
SOX	1733	134%	1057	43%	1700	130%	739	**t**
CO	3434	168%	1655	29%	3458	169%	1283	**t**
NMVOC	845	134%	453	26%	841	133%	361	**t**
NH3	510	154%	244	21%	505	151%	201	**t**
							0	
Total employees	20072	152%	10284	29%	19819	148%	7979	**year**
Total hours	22294581	147%	11689240	30%	21930578	143%	9023651	**h**
Low-skilled	3891707	150%	2012218	29%	3860562	148%	1558974	
Medium-skilled	10736259	148%	5598461	29%	10601727	145%	4332882	
High-skilled	7666616	145%	4078561	30%	7468289	138%	3131795	
Total compensation	888	145%	470	30%	872	141%	362	**m. €**
Low-skilled	133	148%	69	29%	132	146%	54	
Medium-skilled	363	146%	190	29%	358	143%	147	
High-skilled	392	143%	210	30%	382	137%	161	
International impacts								
Change in output	1015676	2%	989216	0%	1018339	3%	992195	**m. €**
of which due to direct final demand	488813	0%	486774	0%	489713	0%	488219	**m. €**
of which due to intermediate demand	526864	5%	502442	0%	528626	5%	503976	**m. €**
CO2	243099	11%	219950	0%	276045	26%	219437	**kt**
Energy use	6079822	11%	5392117	-2%	6652719	21%	5484948	**TJ**
CH4	1636711	10%	1424491	-5%	1760523	18%	1493936	**t**
N2O	69695	13%	60112	-3%	73566	19%	61864	**t**
NOX	70546	13%	60976	-2%	74286	19%	62311	**t**
SOX	969634	11%	896192	3%	1061457	21%	873927	**t**
CO	2818664	21%	2329935	0%	2964605	27%	2329916	**t**
NMVOC	813900	10%	686233	-8%	860285	16%	742890	**t**
NH3	201885	3%	179744	-8%	211177	8%	195289	**t**
Land use	32049	9%	26446	-10%	33862	16%	29268	**1000ha**
Water use	69473032	10%	56821445	-10%	76398946	21%	63288955	**1000m^3**
Biomass	125532	10%	107554	-6%	130732	14%	114419	**1000t**
Fossils	530805	7%	452671	-8%	600944	22%	494057	**1000t**
Minerals	476785	-24%	476241	-24%	542964	-14%	629230	**1000t**
Workhours	13499706907	20%	10773630244	-4%	15623014006	39%	11207704302	**h**
Employees (FTE)	7788177	18%	6440223	-2%	8909600	35%	6600465	**year**
Employee compensation	231353	3%	230901	3%	227189	1%	225099	**m. €**

APPENDIX H: ECONOMIC CHANGES OF FINNISH SECTORS WHEN DIFFERING REGIONAL FUND ALLOCATION IS USED FOR FINNISH FUNDS