Department of Industrial Management and Logistics
Division of Engineering Logistics
Faculty of Engineering
Lund University

Development of a Simulation Tool to Support the Process of Setting Climate Targets

– An Exploratory Study at IKEA

Authors:	Patrik Sander Simon Skoog	
Supervisors:	Andreas Ahrens	IKEA of Sweden
	Eva Berg	Department of Industrial Management and Logistics, Lund University
Examiner:	Jan Olhager	Department of Industrial Management and Logistics, Lund University

Department of Industrial Management and Logistics
Division of Engineering Logistics
Faculty of Engineering
Lund University
Box 118
SE-221 00 Lund
Sweden

Master's Thesis, Division of Engineering Logistics

Acknowledgement

This master's thesis was written as the final part of our education in Mechanical Engineering at the Faculty of Engineering, Lund University. Our research has been a part of a project at Inter IKEA which purpose is to develop ambitious climate targets and securing that IKEA will limit the effects of climate change. The project team, of which we took part, greeted us with great hospitality and made this project both educational and fun. Therefore, we would like to state our sincere gratitude to IKEA and especially everyone who took part in the project team, we could not have wished for a better environment to end our studies in. Furthermore, were two other students, Pernilla Agné and Caroline Vernet, also writing their master's thesis as part of the project. We would like to thank you for your valuable contribution that made our research possible.

A vital success factor for this project has been Andreas Ahrens, the project leader and our supervisor and mentor at IKEA, who were willing to sacrifice a lot of time to disseminate his knowledge to us. Nothing but the utmost gratitude and respect to him.

Furthermore, we want to thank Eva Berg, our supervisor at the Department of Industrial Management and Logistics, for valuable feedback and support during the thesis.

Finally, huge thanks to all our friends and family who made five years of study into an enjoyable memory that, hopefully, will never perish.

Lund, June 2017

Patrik Sander Simon Skoog

Abstract

Title: Development of a Simulation Tool to Support the Process of Setting Climate Targets – An Exploratory Study at IKEA

Authors: Patrik Sander and Simon Skoog

Division: Engineering Logistics

Supervisors:

Andreas Ahrens	IKEA of Sweden
Eva Berg	Department of Industrial Management and Logistics, Lund University

Keywords: system dynamics modelling, simulation, sustainability, policy evaluation, science-based targets, value chain, scope 3

Background: The world's governments agreed in 2010 to work towards limiting global warming to a two-degree warming compared to pre-industrial temperatures with the presumption that this would suffice in order to avoid the worst effects of climate change. Meeting this goal would, according to The Intergovernmental Panel on Climate Change, require a reduction of global emissions by 41–72 percent by the year 2050. In order to reach this goal, all companies are required to minimise emissions throughout the whole value chain. To assess policies and actions required to achieve said reduction by 2050, simulation is deemed applicable.

Purpose: The purpose of this master's thesis is to develop a simulation tool to support the process of setting climate targets with respect to indirect emissions resulting from value chain activities.

Research Questions:

1. Which are the emission drivers relating purchased goods and services, and use of sold products in IKEA's Scope 3 emission system?
2. Which parameters can be applied to allow steering on the emission drivers?
3. How should a simulation tool be designed to address and capture the behaviour and characteristics of the emission drivers in the Scope 3 emission system?

Methodology: The research study consists of a systems approach, abductive methodology and a single-case strategy. To understand the underlying problem, literature review, data gathering and workshops were conducted. A gap analysis was then conducted to analyse emission drivers found both in literature and at the workshops. A simulation model was then constructed by combining spreadsheet and system dynamics modelling.

Results: The result is a spreadsheet simulation model which can be used as a policy evaluator on all quantifiable drivers found in the scope.

Conclusion: The study found the major driver of the identified scope 3 emissions. The performed gap analysis, however, showed that the problem did not lie in identifying the driver but rather to quantify their impact on the system. By not being able to quantify all drivers' impacts, steering parameters will be limited to quantifiable drivers. A framework for developing a simulation tool to support the climate target process is suggested and consists of five ingoing factors; (1) requirements, (2) emission drivers and steering parameters, (3) GHG inventory, (4) scenarios and policies, and (5) the business as usual scenario. A benefit of the simulation tool is that it facilitates an iterative, flexible and fact-based approach for setting climate targets. Furthermore, the model mitigates the risk of too optimistic projections as it takes overlap of various policies into consideration. The constructed spreadsheet model is deterministic; thus, it lacks stochastic variables which entail limitations in the accuracy of the simulation results. Furthermore, the scope of the project entails constraints to map all relevant emission drivers required to predict the Scope 3 system behaviour.

Sammanfattning

Titel: Utveckling av ett simuleringsverktyg som understödjer processen att sätta klimatmål – En explorativ studie på IKEA

Författare: Patrik Sander och Simon Skoog

Division: Teknisk Logistik

Handledare:
Andreas Ahrens IKEA of Sweden
Eva Berg Institutionen för Teknisk Ekonomi och Logistik, Lunds Universitet

Nyckelord: system dynamics modelling, simulering, hållbarhet, policyutvärdering, värdekedja, science-based targets, scope 3

Bakgrund: De ledande världsekonomierna kom 2010 överens om att begränsa den globala uppvärmningen till två graders ökning jämfört med förindustriella temperaturer i hopp om att det räcker för att undvika den värsta effekten av klimatförändringar. För att nå detta mål skulle det, enligt The Intergovernmental Panel of Climate Change, krävas en absolut reducering av utsläpp med 41–72 procent till 2050. För att detta ska bli verklighet, måste alla företag reducera utsläpp inom hela värdekedjan. Simulering anses vara ett passande verktyg för att avgöra vilka policys och medel som krävs för att nå dessa mål.

Syfte: Syftet med det här examensarbetet är att utveckla ett simuleringsverktyg som stödjer i processen att sätta klimatmål med avseende på indirekta utsläpp som sker inom värdekedjan.

Frågeställning:

1. Vilka är emissionsdrivarna associerade till köpta produkter och tjänster samt användning av produkter inom IKEA:s Scope 3 emissionssystem?
2. Vilka parametrar är kan nyttjas för att tillåta styrning på emissionsdrivarna?
3. Hur ska ett simuleringsverktyg utvecklas för att adressera och fånga beteendet och karaktärsdragen hos emissionsdrivarna inom Scope 3?

Metod: Den använda forskningsmetoden bygger på ett systeminriktat tillvägagångssätt, en abduktiv metod och enfallsstudie. För att förstå det underliggande problemet har en litteraturstudie, datainsamling samt workshops upprättats. En skiljeanalys tillämpades sedan för att analysera emissionsdrivare som identifierats både under litteraturstudien och workshops:en. Ett simuleringsverktyg utvecklades sedan genom att kombinera kalkylblads- och system dynamics-modellerande.

Resultat: Resultatet består av en kalkylbladsbaserad modell som kan nyttjas för att utvärdera policys på alla kvantifierbara emissionsdrivare identifierade under skiljeanalysen.

Slutsats: Studien fann de största emissionsdrivarna inom projektets omfattning av Scope 3. Skiljeanalysen visade på att problemet inte låg i att finna emissionsdrivarna utan snarare att kvantifiera deras påverkan på systemet i dess helhet. Då kvantifiering inte kunde göras på somliga emissionsdrivare blev även styrparametrarna limiterade till att enbart kunna påverka kvantifierbara drivare. Drivarna och styrparametrarna utgjorde sedan en god grund för att utveckla ett simuleringsverktyg. Ramverket för simuleringsverktyget bestod av; (1) kravspecifikation, (2) emissionsdrivare och styrparametrar, (3) växthusgasinventarium, (4) scenario och policys samt (5) ett ”business as usual” scenario. En förmån med simuleringsverktyget är att det underlättar iterativ, flexibel och faktabaserad tillvägagångssätt för att sätta klimatmål. Vidare reducerar modellen risken av att sätta för optimistiska projiceringar då den tar hänsyn till eventuella överlapp av policys. Simuleringsverktyget är deterministisk, därav saknas stokastiska variabler vilket medför begränsningar i simuleringsresultatens precision. Dessutom utgör projektets avgränsning en begränsning för att kartlägga alla emissionsdrivare som krävs för att förutse Scope 3 emissionssystems beteende.

Table of Content

Table of Abbreviations

Abbreviation	Full Name
2DS	2°C scenario
AR5	Fifth Assessment Report
BAU	Business as Usual
CCS	Carbon Capture and Storage
CDP	Carbon Disclosure Project
CH_4	Methane
CO_2	Carbon Dioxide
CO_2 eq	CO_2 equivalents
EF	Emission Factor
EU	European Union
F-gases	Fluorinated Gases
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
h	Hours
HFCs	Hydrofluorocarbons
IEA	International Energy Agency
IEA 2DS	IEA 2°C scenario
IEA 6DS	IEA 6°C scenario
IPCC	The Intergovernmental Panel on Climate Change
kg	Kilograms
kWh	Kilowatt Hours
LCA	Lifecycle Analysis
N_2O	Nitrous Oxide
PFCs	Perfluorocarbons
PP	Polypropylene
RS	Relative share
SBT	Science Based Target
SBTi	Science Based Target initiative
SF_6	Sulphur Hexafluoride
SSI	Supplier Sustainability Index
TWh	Terawatt hours
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VBA	Visual Basic Advanced
VV&T	Validation, Verification and Testing
W	Watt
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Institute
WWF	Word Wildlife Foundation

List of Figures

List of Tables

1 Introduction

This chapter gives an introduction to the background of the research topic, followed by a problem description and the purpose of the research. Furthermore, are focus and delimitations of the study presented as well as its intended target group and contributions to research. Lastly, is an overview of the structure of the report given to navigate the reader through the research.

1.1 Background

IKEA is going all in to tackle climate change. Sustainability is one of the seven IKEA strategies and is critical to the overall success of the company. One of the challenges lies in the aim to use fewer resources and ensure that the materials used are produced in a way that is good for people and the planet. Meanwhile, the business is growing, with more stores opening and more products being sold, the demand for these resources can only increase.

To tackle this, IKEA is committed to set ambitious targets that encourage innovation with measurable progress on how it operates within the limits of the planet. By August 2020, IKEA Group (meaning stores and warehouses) will generate as much renewable energy as they consume. Additionally, IKEA Group signed up to the Science Based Targets (SBT) initiative, committing to set targets consistent with the level of decarbonisation required to limit warming to less than 2°C when compared to pre-industrial temperatures. The initiative is a partnership between CDP (former Carbon Disclosure Project), United Nations (UN) Global Compact, World Resource Institute (WRI) and World Wildlife Foundation (WWF), which helps companies determine the levels of decarbonisation required to reduce their impact on the climate. By committing to SBT, IKEA creates climate target transparency and allows them to position itself as a leader in corporate sustainability.

SBT are divided into three scopes. Scope 1 and 2 are directly connected to the energy used in day-to-day operations, e.g. stores, offices, warehouses etc. This is, however, only a small part of the IKEA total footprint (and most greenhouse gas (GHG) emissions can be traced to Scope 3; indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities not covered in Scope 2, outsourced activities, waste disposal, etc. As can be seen in Figure 1.1, this is where IKEA Range & Supply and IKEA Industry can make an impact.

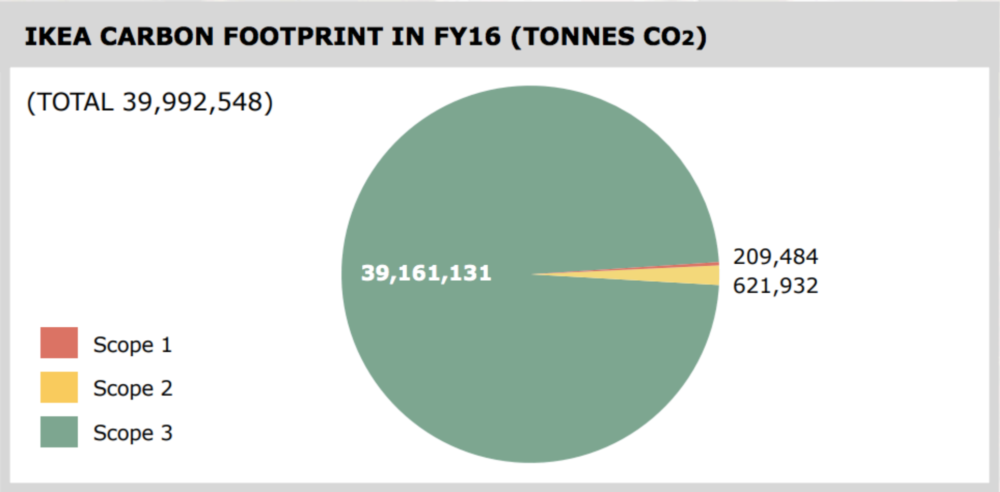


Figure 1.1. The total IKEA carbon footprint for Scope 1, 2, and 3 (IKEA, 2016, p.42).

To measure and follow-up on climate targets on a total IKEA Range & Supply and Industry level, as well as on individual IKEA unit level and further sub-levels, IKEA needs data and scenario analysis on their footprints as well as a goal framework that is both possible to follow-up and forecast.

1.2 Company Description

Inter IKEA Group is a group of companies, headed by Inter IKEA Holding B.V. The purpose of the group is to secure continuous development, expansion, long life and improvement of the IKEA concept (Inter IKEA, 2017a). Inter IKEA Systems B.V. owns the IKEA concept and manages the worldwide franchise concept (Franchisor IKEA, 2017).

Further decoupled from Inter IKEA Holding B.V. is IKEA Industry AB, which holding company is IKEA Industry Holding B.V. (Inter IKEA, 2017b). IKEA Industry AB produces two types of furniture: light-weight or board based products, and solid wood products. The company operates in 10 countries with 40 production units (ibid).

IKEA Range & Supply AB are responsible for supplying and developing the IKEA product range (Inter IKEA, 2017c). That means that they operate throughout the whole value chain, from raw material to products end of life. Two core units operate directly under IKEA Range & Supply; IKEA Supply AG (Supply) who owns the goods in the distribution centres, and IKEA of Sweden AB (Range) (ibid). Further down the chain lies two other companies; IKEA Food Services AB who are responsible for the IKEA restaurants and the Swedish food market (IKEA, 2017), and IKEA Components AB who are responsible for the development of furniture components, new raw material concepts, and packaging solutions for furniture (Bloomberg, 2017). The company of interest for this project and research are the encircled companies in Figure 1.2.

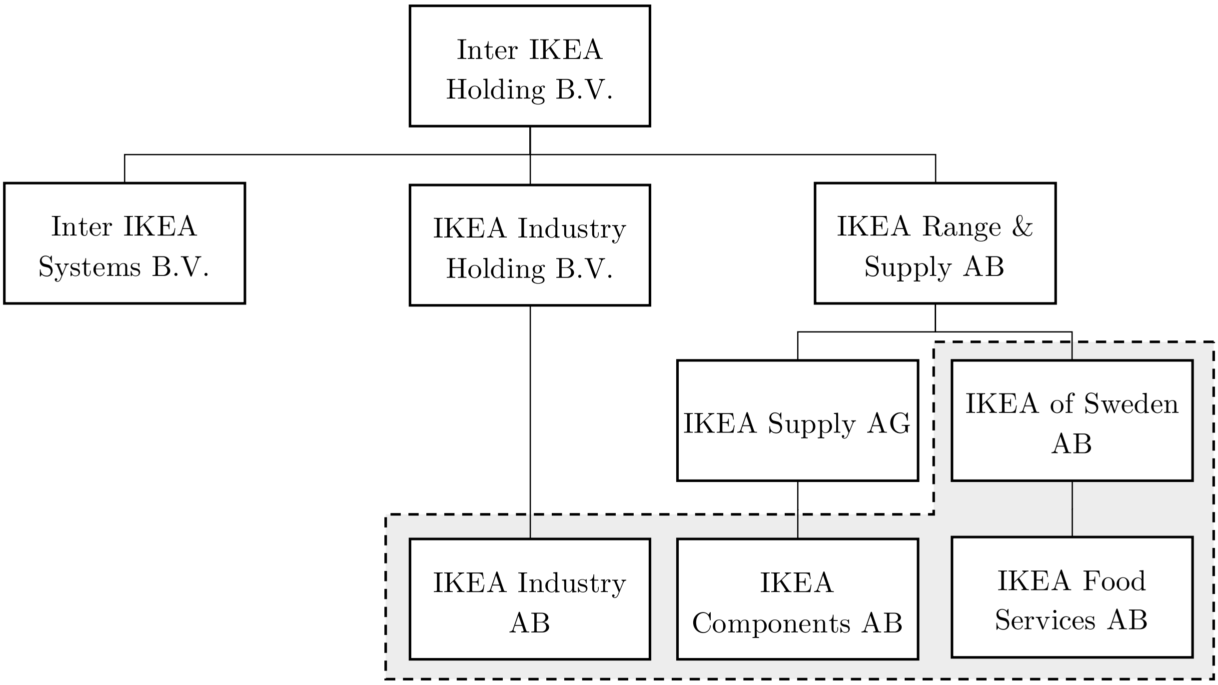


Figure 1.2. The concerned companies for this project and research.

1.3 Problem Formulation

IKEA needs support to identify and analyse relevant data as well as developing a model to base its climate targets on for its Scope 3 emissions. Derived from identified stakeholder needs and relevant data, the model will support and facilitate the development of strategies to manage and reduce indirect value chain emissions. The developed model will primarily be used internally to;

- develop a better understanding and gain insights of the Scope 3 emissions system,
- to compare various plans and scenarios before implementation,
- to predict behaviours of the Scope 3 emissions system and
- to aid decision-making processes.

1.4 Purpose

The purpose of the master's thesis is to develop a simulation tool to support the process of setting climate targets with respect to indirect emissions resulting from value chain activities.

1.5 Research Questions

To fulfil the purpose of the study, the following research questions are to be answered;

1. Which are the emission drivers relating purchased goods and services, and use of sold products in IKEA's Scope 3 emission system?
2. Which parameters can be applied to allow steering on the emission drivers?

3. How should a simulation tool be designed to address and capture the behaviour and characteristics of the emission drivers in the Scope 3 emissions system?

1.6 Focus and Delimitations

The three scopes in the Greenhouse Gas Protocol, on which the SBT are based upon, are presented in Figure 1.3.

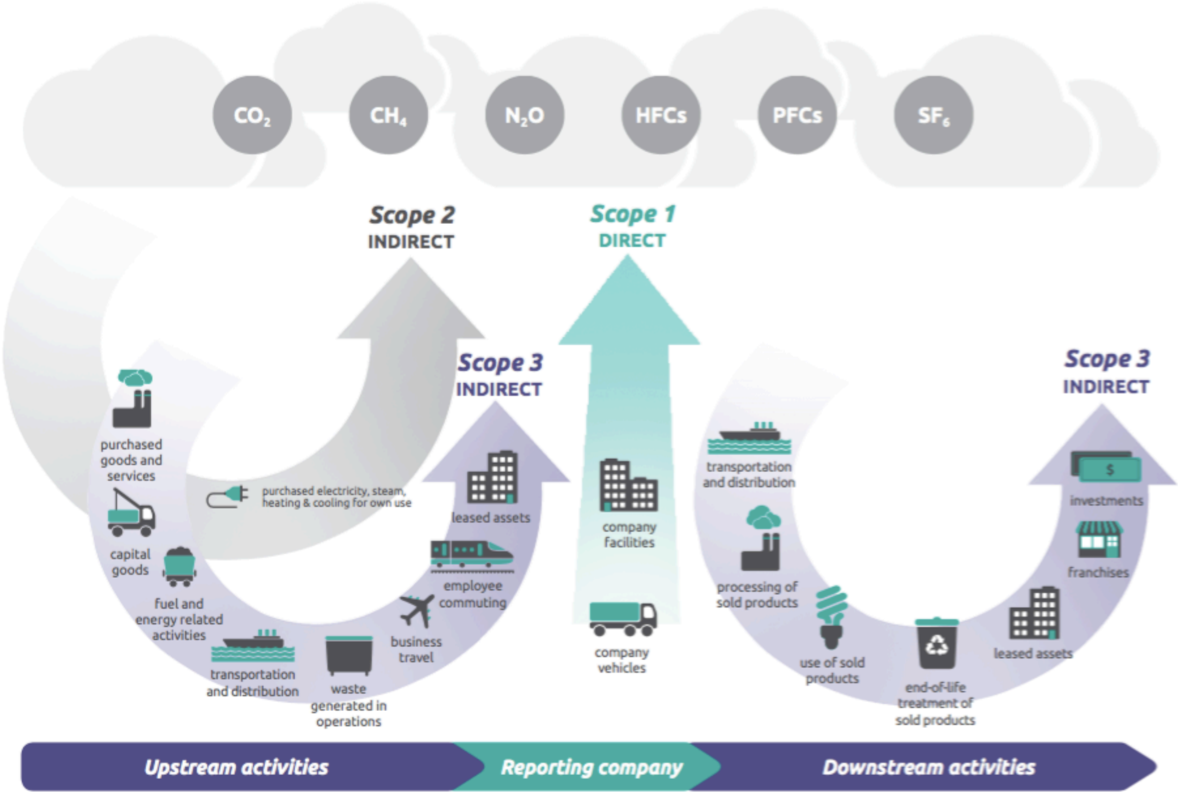


Figure 1.3. The three scopes in the GHG Protocol (GHG Protocol, 2011, p.5).

The scope of the project is delimited to encompass the indirect emissions that occur in the company's value chain (Scope 3), excluding direct emissions (Scope 1) as well as indirect emissions from the generation of purchased energy consumed (Scope 2). As Scope 3 is defined as the specific activities related to the company's value chain, the scope goes beyond just the supply chain.

However, of the Scope 3 emission categories, the primary focus is set on the value chain activities where the preponderance of emissions is found within this project. These consist primarily of the supply chain emissions relating to purchased goods and services. In addition to these, the emissions associated with the use of sold products are included in the scope of the project.

Delimitations to the scope of activities are predominantly excluded because of the criteria guidance for identifying relevant activities found in Greenhouse Gas Protocol Corporate

Value Chain (Scope 3) Accounting and Reporting Standard (2011). These include e.g. if the activities contribute significantly to the total emissions and how much influence the company has on potential reductions. Activities excluded from the scope of the research are therefore e.g. business travel, employee commuting and end-of-life treatment of sold products.

Using these premises, the scope of the research and simulation tool was predefined in the project to encompass two following emission categories; (1) purchased goods and services, and (2) use of sold products.

Furthermore, the project scope will be focused towards four working groups; IKEA of Sweden, IKEA Components, IKEA Industry and IKEA Food Services.

1.7 Target Group

The target group of this master's thesis is primarily stakeholders within the Inter IKEA Group. In addition, it may be of interest for other companies that have committed to SBT or similar initiatives that involve setting climate targets.

1.8 Contributions

IKEA – support to set, maintain and update climate targets for the Scope 3 emissions by developing a simulation tool.

Academia – extension of research within the area of sustainability simulation, with especially focus on simulation for setting climate targets.

Society – the suggested framework can support other companies in their approach to setting climate targets, ultimately leading to reduced global warming and to a more sustainable society.

The Authors – the research has further deepened the authors understanding in the fields of supply chain management, sustainability and simulation.

1.9 Clarification of Roles in the Project

The project group that was appointed for setting the science-based targets for Scope 3 of the Inter IKEA Group has representatives from the IKEA companies highlighted in Figure 1.2. In addition to these working groups, external support consists of footprint specialists for raw material, food and agriculture as well as with guidance regarding the science-based target methodology. The authors' role in the project was in the form of a supporting function to the working units. Figure 1.4 shows the project organisation where the authors' role is highlighted in grey.

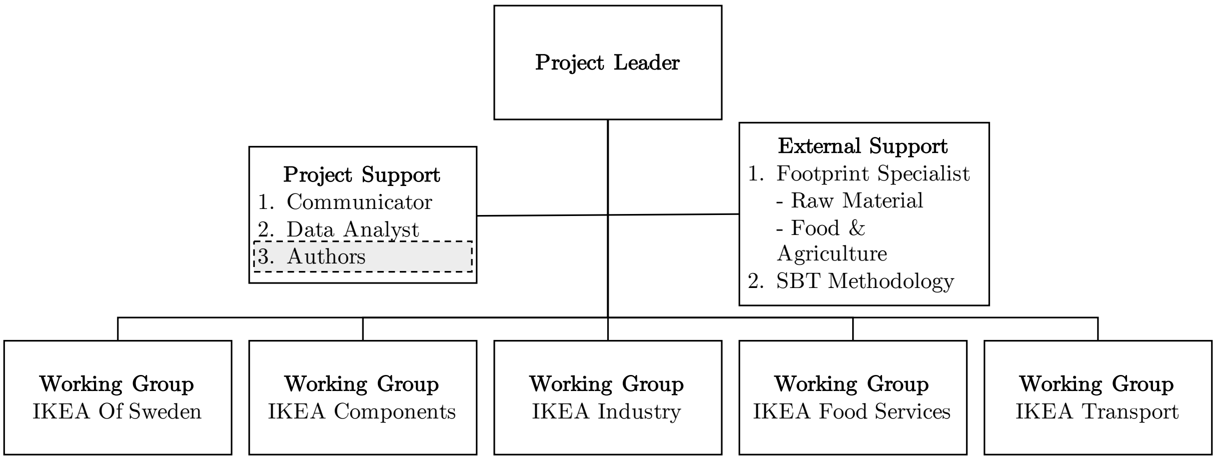


Figure 1.4. The project organisation with the authors' role highlighted in grey.

The expected deliverables of the authors were defined and summarised in the following seven assignments:

1. Support in collection and structuring necessary business data needed for further analysis and simulation
2. Analyse data regarding the GHG footprint and other business data to identify:
    - The right level of data granularity for the different footprints to enable steering and follow-up and match any external data sets (e.g. material emission factors), and
    - Impact of potential improvements to reduce greenhouse gas emission, e.g. making first tier suppliers 100 percent renewable
3. Analyse external data on goals, policies, etc. for energy and climate on country/region level to identify contributions to reduce the footprint from external factors, e.g. if a country has a goal towards 100 percent renewable energy and what impact would have on the suppliers in that country.
4. Support in defining a framework for measuring and follow-up of absolute and relative climate targets on a total IKEA Range & Supply and Industry level, as well as on individual IKEA unit level and further sub-levels.
5. Develop a simulation model, where the IKEA GHG footprint can be simulated based on future growth and key parameters regarding materials, suppliers (production), transport, and customer use of products – all with the ambition to make IKEA's contribution to stay within a global warming of 2°C or less.
6. Support in development of climate targets by providing critical facts and insights from the analysis of the different data sets and the simulation model.
7. Create a road map for how to both refine the data quality at IKEA as well as refining the simulation model.

The main focus for the authors was the fifth deliverable, development of a simulation tool. To further depict which role the simulation tool has in the project, the process of setting the targets is shown in Figure 1.5. The role of the authors is concentrated on the development of the simulation tool, any activities outside the highlighted area in the figure are therefore only as support to the other stakeholders in the project.

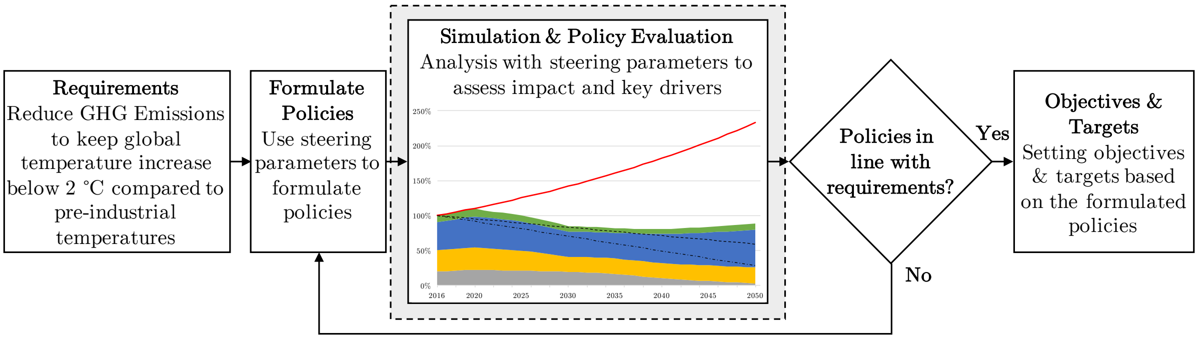
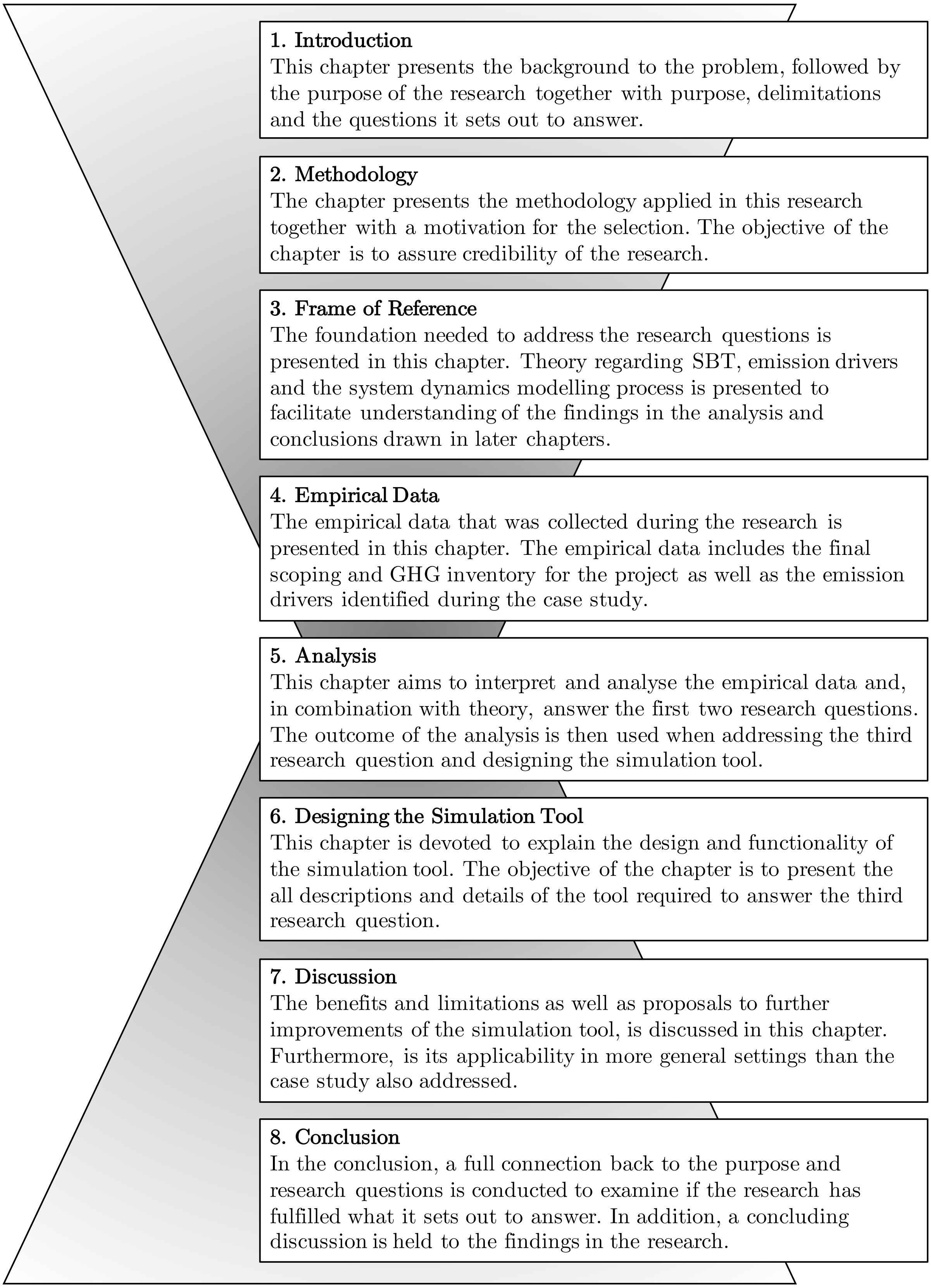


Figure 1.5. The process of setting climate targets in the project. The main focus of the research is highlighted in grey.

1.10 Report Structure

The report is structured in eight chapters and composed to initially give an overview of the general field of the research and to enhance understanding of the problem in context. The specific setting for the study is then presented together with the focus areas and methodology for the research. Lastly, the findings of the research are presented and discussed, followed by conclusions of the implications of the study for the general field. A more detailed description of the chapters and their role is presented in Figure 1.6.



1. Introduction
This chapter presents the background to the problem, followed by the purpose of the research together with purpose, delimitations and the questions it sets out to answer.

2. Methodology
The chapter presents the methodology applied in this research together with a motivation for the selection. The objective of the chapter is to assure credibility of the research.

3. Frame of Reference
The foundation needed to address the research questions is presented in this chapter. Theory regarding SBT, emission drivers and the system dynamics modelling process is presented to facilitate understanding of the findings in the analysis and conclusions drawn in later chapters.

4. Empirical Data
The empirical data that was collected during the research is presented in this chapter. The empirical data includes the final scoping and GHG inventory for the project as well as the emission drivers identified during the case study.

5. Analysis
This chapter aims to interpret and analyse the empirical data and, in combination with theory, answer the first two research questions. The outcome of the analysis is then used when addressing the third research question and designing the simulation tool.

6. Designing the Simulation Tool
This chapter is devoted to explain the design and functionality of the simulation tool. The objective of the chapter is to present the all descriptions and details of the tool required to answer the third research question.

7. Discussion
The benefits and limitations as well as proposals to further improvements of the simulation tool, is discussed in this chapter. Furthermore, is its applicability in more general settings than the case study also addressed.

8. Conclusion
In the conclusion, a full connection back to the purpose and research questions is conducted to examine if the research has fulfilled what it sets out to answer. In addition, a concluding discussion is held to the findings in the research.

Figure 1.6. The structure of the report.

2 Methodology

This chapter serves as an introduction to the methodology that has been applied in this research. The ambition of the chapter is to provide sufficient background and motivation for the selected methodologies to assure credibility of the research. For each subsection, a description of different approaches and methodologies is presented, followed by a motivation for the selected ones in this research.

2.1 Research Approach

When studying and researching reality, there are multiple views of when and how to use different methods (Arbnor and Bjerke, 2009). These methodological views are called methodological approaches when put in application. Arbnor and Bjerke (2009) suggests three different research approaches to apply for different methodological views; (1) analytical approach, (2) systems approach, and (3) actors approach.

2.1.1 Analytical Approach

The analytical view is focused on facts where the sole ambition is to explain the factive reality (Arbnor and Bjerke, 2009). Explanations take, ideally, the form of causal relations and factive reality is best described by studying components separately. The overall knowledge is then acquired from the sum of the partial results of the isolated elements. This analytical view is based on the important theoretical assumption that the components of study can be considered as independent of each other. Causal relationships may be verified or falsified by testing hypotheses of contributory factors that make up an effect (ibid).

2.1.2 Systems Approach

In parity with the analytical view, is the systems view founded with the ambition to work up pictures of the factive reality (Arbnor and Bjerke, 2009). However, contrary to the analytical view, the factive reality is best clarified by studying individual components in relation to the whole according to the systems view. It, therefore, disregards the analytical assumption that elements are independent of each other, having a holistic view where the system as a whole determines the behaviour of its components. The underlying assumption of the systems approach is therefore that reality is organised in such a way that the totality differs from the sum of its isolated parts. This means that individual components must be put in context in order for it to be explained and understood (ibid). All systems approaches are committed to holism. Holism respects the profound interconnectedness and relationships between parts, rather than understanding complex problem situations by breaking them down and intervene with the elements (Jackson, 2002).

2.1.3 Actors Approach

The third methodological approach that Arbnor and Bjerke (2009) presents is the actors view and has the ambition to understand reality. A central assumption for the actors view is the existence of a social reality, which means that the reality is not independent of us. In difference to the analytical and systems view, the actors view is not centred around explanations, but rather in understanding social wholes. Furthermore, objectivity only exists as a social construction in the actors view. Objectivity and reality may, therefore, be questioned and changed. Given these fundamentals, the creator of knowledge in the actors view is encouraged to be part of the research whereas in the analytical and systems view it is suggested to act as an observer (ibid).

2.1.4 The Selected Approach

The selected approach for this research was the systems approach. Part of the research objective was to develop a better understanding and gain insights of the Scope 3 emission system. In order to succeed in doing so, and to capture the interconnectedness and relationships between system components, a holistic approach was needed. Since the system approach facilitates a methodology that aims to describe the system behaviour and causal relationships, it was regarded as the most suitable of the approaches suggested by Arbnor and Bjerke (2009).

Since the targeted system by nature consists of strong interactions between the elements, was the analytical approach regarded as inadequate for this research. An analytical approach would have meant that the components could be studied as independent of each other with weak links between them.

Applying the actors view for this research would have meant that the ambition would have been on understanding the social interactions that lead to the result (Arbnor and Bjerke, 2009). As the aim of this research was to develop a simulation model primarily for explanatory purposes, a social-oriented approach was deemed inappropriate. The actors view was therefore not considered as a suitable research approach.

2.2 Research Methodology

2.2.1 Inductive – Qualitative Approach

The aim of the qualitative approach is to understand the phenomenon in its own terms (Kotzab et al., 2005). The initial step of the qualitative path is, therefore, data collection where the researcher usually frames an understanding from observing the phenomenon in its natural setting. The succeeding step is then to describe the phenomenon from the point of view of the observed participants. Descriptions are generated from qualitative techniques such as participant observation, in-depth interviews and focus groups. The third and final step is then to build substantive theory on the description. Inductive analysis is carried out on the qualitative data to create a deeper understanding of the core phenomenon. The analysis typically takes the form of a process model where the dynamic nature of the phenomenon is captured by describing relationships and feedback loops among variables (ibid).

2.2.2 Deductive – Quantitative Approach

In contrary to the qualitative approach, the goal of the quantitative approach is to add on the body of knowledge by generating theory that explains, controls and predicts a phenomenon (Kotzab et al., 2005). The initial step of the quantitative approach is, therefore, to develop a conceptual framework by reviewing appropriate literature. The framework captures relevant variables and expected relationships among them. The next step is formulating a formal theory grounded in previous research. The formal theories are general where predictive statements of the theory can be tested with real-world data of the phenomenon. Finally, data is collected to verify the formal theory and testing the hypotheses formulated by the researcher (ibid).

2.2.3 Abductive – Balanced Approach

Woodruff (2003) presents the abductive approach as a combination of the inductive and deductive approach, see Figure 2.1. The research approach and pathway is determined by the nature of the phenomenon and type of research question that the researcher is set out to answer (Kotzab et al., 2005). In the case of a new and/or complex phenomenon is it often necessary to begin with an inductive approach in order to understand and generate substantive theory while a deductive approach is preferable to develop and test formal theory. A balanced approach is achieved by tracking back and forth between the qualitative and quantitative approaches (ibid).

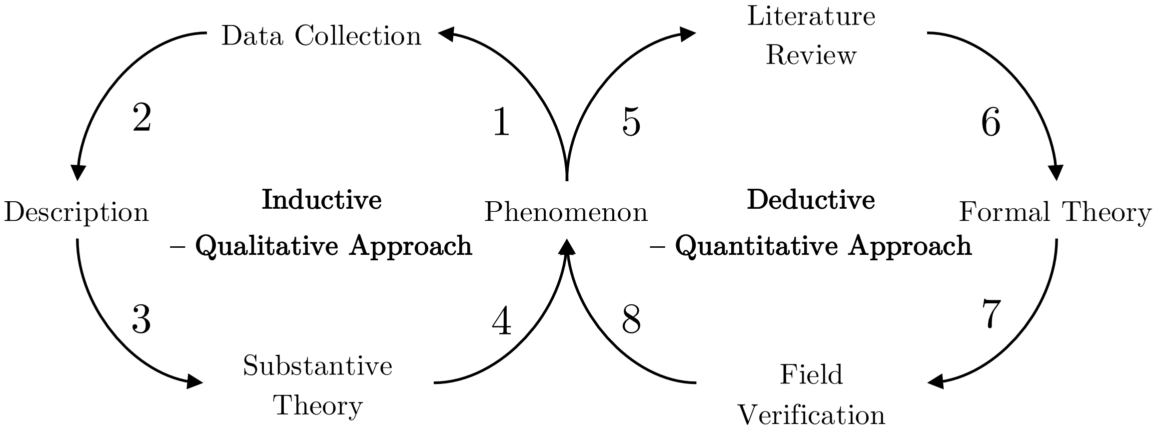


Figure 2.1. The abductive approach (Woodruff, 2003).

2.2.4 The Selected Methodology

Due to the nature of the research questions, an abductive approach was considered to be the most appropriate to be applied for this research. To answer the third research question, which addressed the design of the simulation tool, a deductive approach was taken to assess solution alternatives. When addressing the first two research questions, targeted at identifying the emission drivers and how they could be modelled, the approach was primarily inductive with a focus on qualitative data collection. However, as Kotzab et al. (2005) advocates, the abductive approach is a suitable research approach for new and/or complex phenomenon. Thus, a balanced approached was deemed necessary because simulation in the context of indirect value chain emissions is a relatively unexplored area.

2.3 Research Strategy

When putting strategy in the context of research, Denscombe (2010) presents the following components as requirements:

- An overview, the bigger picture that determines the approach to the research (a research paradigm).
- A plan of action that offers the best prospects of success (a research design).
- A goal that can be achieved and which is clearly identified (a research problem).

2.3.1 Research Strategies

Yin (2009) presents experiment, survey, archival analysis, history and case study as examples of different research strategies. Every strategy may be used for the purposes of exploratory, descriptive or explanatory research. When determining the choice of research strategy, there are three conditions to consider;

1. The type of research question posed,
2. The extent of control over behavioural events and
3. The degree of focus on contemporary or historical events.

In Table 2.1 are these conditions presented with its corresponding relation to the research strategies (Yin, 2009).

The first condition to consider is the type of research questions that will be addressed. In the case where the focus is on “what” questions, all research strategies may be suitable. These questions can, however, be categorised into two types. The first type of “what” questions are exploratory and arise when the goal is to develop relevant hypotheses and propositions for further analysis. The second type of “what” questions may be formulated as “who” and “where” (with their derivatives “how many” or “how much”). Surveys or archival analysis may be suitable for these types of research questions if the aim of the research is to describe a phenomenon or be predictive of its behaviour. “How” and “why” questions are usually of explanatory character where case studies, histories, and experiments are likely to be preferred as research strategies (ibid).

Table 2.1. Research strategies (Yin, 2009).

Method	(1) Form of Research Question	(2) Requires Control over Behavioural Events?	(3) Focuses on Contemporary Events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/no
History	How, why?	No	No
Case Study	How, why?	No	Yes

In case the research is focused on “how” and “why” questions, the two other conditions may be used to further differentiate the strategy for deciding between experiment, history and case study. A case study is preferred when examining contemporary events since it facilitates direct observation and interviews with individuals involved in the events.

Denscombe (2010) uses the research purpose as guidance as to when different research strategies may be suitable. Experiment is appropriate when the purpose of the study is to identify the cause of something or observe the influence of specific factors. Survey may be used when the purpose is to measure some aspect of a social phenomenon or trend or to test a theory by gathering facts. When the objective is to understand complex relationships as they operate in their natural setting, case study is a suitable research strategy.

2.3.2 The Selected Strategy

The first and second research questions are formulated to set out to answer *which* the emission drivers and steering parameters are. These are exploratory in nature with the objective to be used for further analysis when implemented in the simulation tool and, thereby, addressing the third research question. It sets out to identify an appropriate way of *how* the simulation tool should be designed to enable modelling of the behaviour and characteristics of the Scope 3 emission system. As Yin (2009) argues, is case study a suitable research strategy for these kinds of questions when dealing with contemporary events without the need to control behavioural events.

Given these premises, was case study selected as the strategy for this research. This was also based on the suggestion provided by Dencombe (2010) who presents case study as a suitable strategy when the objective is to study the phenomenon in its natural setting. Furthermore, a significant part of this research was targeted at studies to investigate and identify the emission drivers and how they may be steered. This kind of early, exploratory in-depth study when the variables are still unknown and the phenomenon is not understood is a characteristic that Meredith (1998) uses as one of the outstanding strengths of case studies.

2.3.3 Case Study Designs

Yin (2009) presents four types of design to consider when applying case study as a research strategy, based on a two by two matrix. One dimension refers to the number of cases in the research, differentiating between single and multiple case design. The other consists of the number of units of analysis involved in the case or cases, denoting holistic for single-unit of analysis and embedded for multiple units of analysis (ibid).

Single case studies have the advantage of allowing the researcher for greater depth of observation (Voss et al., 2002). Limitations of the single case study involve generalizability of conclusions, models or theory as well as a higher risk of single event misjudgement, and of exaggerating easily available data. Multiple case studies have the benefit of reducing this risk through cross-case analysis where the data and event may be compared in different settings. Constraints in resources may, however, reduce the depth of the research (ibid).

A holistic design is appropriate when the case study does not have distinguishable subunits that can be identified (Yin, 2009). To incorporate multiple subunits of analysis, as in the embedded design, enhances opportunities for extensive analysis. There are, however, a greater risk of losing the holistic aspects if too much focus is directed towards these subunits (ibid).

2.3.4 The Selected Case Study Design

A single case study was selected for this research, primarily due to the fact that it allows for greater depth of analysis of a Scope 3 emission system. When identifying emission drivers and modelling the system, a single case decreases the risk of neglecting influences between the targeted system elements. Another reason for selecting a single case was the restricted resources and time constraints of this research.

The unit of analysis for the case study is the process of development of a simulation tool that facilitates policy evaluation when setting climate targets for value chain activities. A holistic approach was therefore preferred since the simulation tool was targeted to capture the global nature of emissions in the value chain of the organisation.

The outcome of these selections leads to a Type 1 case design, single-case holistic design, as suggested by Yin (2009).

2.4 Research Design

2.4.1 Ways to Study a System

Law and Kelton (2000, p.3) define a system as “a collection of entities, e.g. people or machines, which act and interact together toward the accomplishment of some logical end”. In many circumstances, these relationships and interactions are of interest to study in order to gain insights of the system behaviour or to predict the performance under new conditions. To do so, Law and Kelton (2000) proposes different ways to study a system, see Figure 2.2.

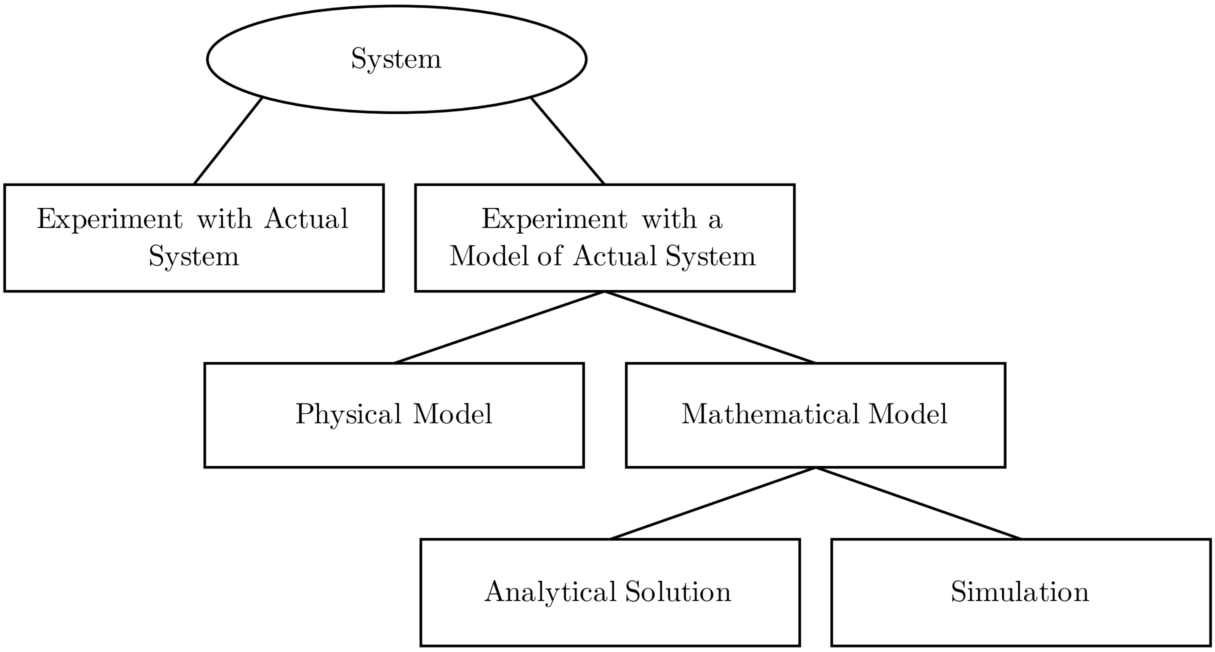


Figure 2.2. Ways to study a system (Law and Kelton, 2000, p.4).

When selecting an appropriate method for studying a system, the first decision is to consider if it is feasible and reasonable to alter the system physically or if a model of the system must be used (Law and Kelton, 2000). When using the actual system for experimentation, the validity of the results is indisputable. However, in many situations, it is not possible to do so and a model must be built as a representation of the actual system (ibid). A description of the vibrant system must then be abstracted from reality in order to produce the model (Sokolowski and Banks, 2009). The validity of the model behaviour and outcomes must then be considered (Law and Kelton, 2000).

In the case a model of the system must be used, the second decision is to decide whether a physical or mathematical model will be used to study the system (Law and Kelton, 2000). Physical models are commonly not of interest for operations research and system analysis, but rather for pilot training in cockpits disconnected from aeroplanes or clay models of cars in wind tunnels. The preponderance of engineering or management systems is mathematical models, using logical and quantitative relationships to represent the actual system (ibid).

The third decision, presuming a mathematical model will be used, is to determine whether relationships and quantities can be modelled to get an exact, analytical solution (Law and Kelton, 2000). Such a solution is desirable when it is available and computationally efficient. However, many systems are too complex to be modelled analytically and the system must be studied using simulation (ibid).

2.4.2 The Selected Way to Study a System

The selected way to study the Scope 3 emission system was by simulation. The selection was based on the decision choices that Law and Kelton (2000) presents:

1. **Experiment with Actual vs. Model of the System** – to alter the actual Scope 3 system was not feasible for this research and a model had to be constructed. In addition to this, the tool had to facilitate policy evaluation of future scenarios. The time aspect of experimentation with the actual system was therefore not sufficient.
2. **Physical vs. Mathematical Model** – a mathematical model was used since no way of designing a physical model was considered reasonable.
3. **Analytical Solution vs. Simulation** – to capture all interrelationships and influences between system elements in the Scope 3 system, the system was regarded as too complex for an analytical solution. Simulation was therefore used to study the system.

2.4.3 Simulation Modelling

Sokolowski and Banks (2009, p.5) defines a simulation as “an applied methodology that can describe the behavior of that system using either a mathematical model or a symbolic model.” Modelling and simulation may, therefore, be applied in a number of different application areas including analysis, experimentation, and training (ibid).

Particular tools may be used to study different types of simulation models. For the sake of distinguishing these, Law and Kelton (2000) classifies simulation models along three different dimensions:

Static vs. Dynamic

Static simulation models represent a system at a specific time whereas dynamic simulation models are time-varying representations of the system (Law and Kelton, 2000).

Deterministic vs. Stochastic

Deterministic simulation models have no probabilistic components, meaning that the when the input and relationships in the model are specified, the output of the simulation is already determined (Law and Kelton, 2000). If the system includes probabilistic components, a stochastic simulation model is suitable to capture the randomness in the system behaviour (ibid).

Continuous vs. Discrete

Discrete systems are systems where variables change state instantaneously at separate points in time (Law and Kelton, 2000). Continuous systems are, on the other hand, systems where the state of the variables changes continuously over time (ibid). Common differentiation is discrete event and continuous simulation. The concept of variable change between the simulation types is depicted in Figure 2.3.

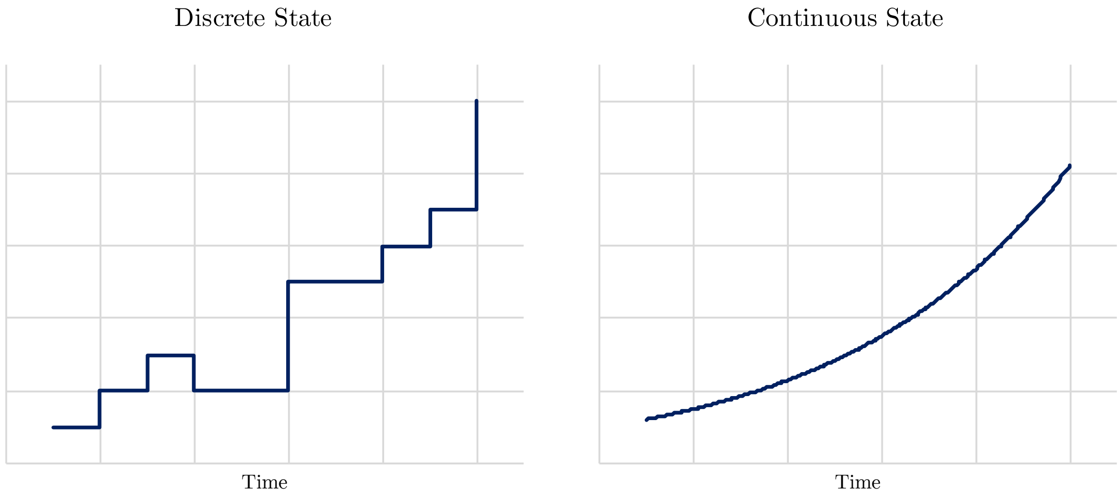


Figure 2.3. The difference in the state of variable change between discrete and continuous simulation.

2.4.4 The Selected Simulation Modelling

This research used a dynamic, deterministic and continuous simulation model. In conformity with the process for choosing simulation as the way to study the Scope 3 system, the selected simulation modelling was motivated using the alternatives suggested by Law and Keltion (2000):

1. **Static vs. Dynamic** – since simulations have to evaluate future policy scenarios, the time dimension is a critical component of the simulation model. Thus, a dynamic approach was deemed necessary.
2. **Deterministic vs. Stochastic** – the Scope 3 system involves numerous variables that would suggest that they have probabilistic behaviour. A stochastic simulation model would, therefore, have been the most suitable alternative when mirroring their influence in the system. However, due to the comprehensive scope of the research in combination with high uncertainty of accurate variable distributions, a deterministic approach was selected.
3. **Continuous vs. Discrete** – to capture the continuous processes and rate of change of the variables in the Scope 3 system, continuous simulation was selected.

2.4.5 Simulation Modelling Approaches

System Dynamics

Coyle (1996, p.10) gives the following definition of system dynamics; “System dynamics deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour and designing robust information feedback structures and control policies through simulation and optimisation.”. Sterman (2000) describes it as a set of conceptual tools which provides guidance on the structure and behaviour of complex systems as well as a rigorous modelling method to build formal computer systems.

Discrete Event

Discrete event simulation is, as previously mentioned, a method where variables changes state instantaneously at discrete moments in time (Law and Kelton, 2000). These variables, called state variables, completely describe the state of the system is at any given point in time (Sokolowski and Banks, 2009).

Agent-Based

No universal definition is accepted in this area (Borshchev and Filippov, 2004). However, one feature differentiates agent-based modelling from system dynamics and discrete event which is that “agents” essentially are decentralised. This means that the global system behaviour of an agent-based model is not pre-defined. Instead, the dynamics emerge from the behaviour at an individual level (ibid).

When considering which approach to choose, Borshchev and Filippov (2004) suggests considering which level of abstraction the different approaches has. This relationship is represented in Figure 2.4. Discrete event modelling is commonly applied at low to middle abstraction (high to medium level of detail) with application areas such as factory floor and warehouse simulation. Agent-based modelling is represented at all abstraction levels. Agents may represent objects ranging from e.g. pedestrians or cars at a low abstraction level up to competing companies at a high level. System dynamics are mainly found among applications on a middle to high abstraction level, ranging from supply chains up to ecosystems and population dynamics (ibid).

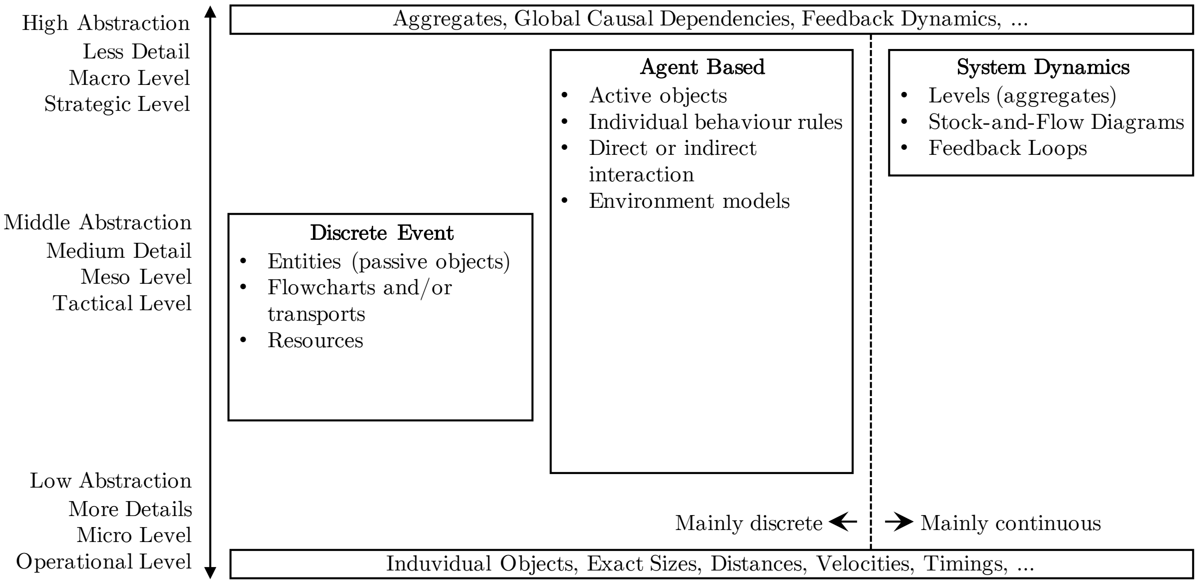


Figure 2.4. Approaches in simulation modelling on abstraction levels (Adapted from Borshchev and Filippov (2004)).

Spreadsheet Model

A spreadsheet model is a type of computer model that is implemented via a spreadsheet (Ragsdale, 2010). Spreadsheet models may be used for strategic or operations planning, many times simultaneously (Smith, 2003). While logistic-specific software has many advantages for analysing supply chain problem, they may not always provide sufficient flexibility. Spreadsheets allow for analysis from many perspectives while having the additional benefit of providing graphical output in form of maps, charts and graphs. Spreadsheet could be continually modified and adjusted as new insights and knowledge are acquired from the modelled system. Higher complexity can be integrated into the model as new situations and options are identified (ibid).

Simulation Approaches in the Context of Value Chain Emissions

A literature review of simulation modelling for sustainability reveals that various applications areas already have been covered (Moon, 2017). Categories covered are e.g. energy, land use, manufacturing, supply chain, sustainable development, transportation as well as waste, recycling and reuse. The most frequent application areas among these are manufacturing and supply chain. Within manufacturing, plans and scenarios for reducing energy consumption, GHG emissions and material uses has been investigated using simulation models. Applications of simulation for sustainable supply chains include e.g. designing desirable green supply chains with emission control as a basis (ibid).

The major methods of simulation modelling for sustainability are discrete event, agent-based simulation and system dynamics (Moon, 2017). However, there are cases where simulation modelling has been adopted to complement other tools. Another trend in the simulation community is also the adaption of hybrid simulation models where two or more simulation methods are combined. The benefit of such an approach is that it allows for representation of multiple viewpoints (ibid).

2.4.6 The Selected Simulation Modelling Approach

This research used a combination of system dynamics and spreadsheet modelling as simulation modelling approach. This was due to the combinatorial benefits of the two approaches. System dynamics provides a systematic approach to facilitate the qualitative mapping of the system, which was crucial to answer the first two research questions. Spreadsheet modelling offers high flexibility to be adapted when new information and insights are gained. Due to the scope and time constraint of this research, the model construction process was partially carried out simultaneously as qualitative data collection. This required high flexibility in the adaption of new simulation logic to be implemented when new requirements and system knowledge was acquired. Further description of the applied modelling process is later given in Section 3.3 System Dynamic Modelling Process. To answer the third research question, the adaption of these, as well as the resulting approach for simulation of the Scope 3 system, is explained in Chapter 6 Designing the Simulation Tool.

2.4.7 Data Collection

Source of Evidence

Yin (2009) presents six sources of evidence that are the most commonly used for case studies; documentation, archival records, interviews, direct observations, participant-observation, and physical artefacts. Documentation has the advantages of being exact and stable, meaning that they recurrently may be reviewed. Documents may take a variety of forms ranging from administrative documents like progress reports and other internal records to formal studies of similar cases. Archival records also have the benefit of being stable and are usually quantitative, often taking the form of computer files and records. Interviews bring the advantage of being targeted, meaning that it could be focused directly on the topic of the case study (ibid).

Participatory research is a method for planning and conducting research with the people whose life-world and meaningful actions are under study (Bergold and Thomas, 2012). The advantage of participatory research is that the participants have first-hand knowledge of the field. Data collection should, therefore, build on their everyday experiences and often take the form of interviews or focus groups (ibid). Focus group interviews are a form of group interview that is structured in a way where selected participants contribute with detailed opinions and knowledge from a specific topic (Bader and Rossi, 2002). This kind of interview is an effective way to stimulate new ideas and simultaneously build interest among the participants. Additional benefits of focus group interviews are that discussions provide detailed qualitative data as well as enabling participants to contribute without much preparation or effort (ibid).

Quantitative and Qualitative Research

Silverman (2015) distinguishes quantitative research as involving numerical analysis of the relationship between variables while qualitative research focuses on verbal descriptions of real-life situations. These differences are summarised in Table 2.2 (ibid).

Table 2.2. Differences between quantitative and qualitative research (Silverman, 2015).

Quantitative Research	Qualitative Research
Generates data that allow numerical analysis	Describes phenomena in context
Uses statistical calculations	Interprets processes or meanings
Uses statistical software and pre-stated scales	Uses theoretically based concepts
Seeks explanation and correlation	Seeks “understanding”

The data used in quantitative research are usually in the form of numbers from precise measurement whereas it is in the form of words and images from documents, observations and transcripts for qualitative research (Neuman, 2014).

Bryman and Bell (2011) suggests a mixed method (also called triangulation) as a combination of quantitative and qualitative methods. A mixed method usually consists of an exploratory qualitative study to identify constructs for a quantitative research. In this case, the qualitative research may provide hypotheses to be tested in a quantitative study. Qualitative research could also bring in-depth knowledge to aid measurements for succeeding quantitative research (ibid).

2.4.8 Data Collection in this Research

In this research, the primary sources of evidence were focus group interviews and archival records. Focus group interviews were used to facilitate qualitative data collection, predominantly devoted to address the first two research questions. A list of the project stakeholders that participated in the focus group interviews is presented in Table 2.3. Quantitative data collection consisted of archival records as input for the developed simulation tool.

Table 2.3. List of project stakeholders.

Stakeholder Position	**IKEA Unit**	**Description of Role**
Project Leader	IKEA of Sweden	Project Leader/Coordinator
Category Analyst	IKEA of Sweden	Support with data analysis for all IKEA units
Specialist for emission quantification: agriculture & food	External	Support with estimation and quantification of non-measurable emissions
Specialist for emission quantification: raw materials	External	Support with estimation and quantification of non-measurable emissions
Specialist on Science-based Target methodology	External	Support in training project team on Science-based Target methodology as well as guide throughout process to prepare the targets before final quality review by Science-based Target Initiative
Sustainability Manager – Category Area	IKEA of Sweden	Responsible for IKEA of Sweden goal development
Sustainability Leader	IKEA Components	Responsible for IKEA Components goal development
External Master's Thesis Student (not author)	IKEA Components	Support with data analysis, projections and target development
External Master's Thesis Student (not author)		
Project Support	IKEA Food Services	Support for IKEA Food Services goal development
Sustainability Developer	IKEA Food Services	Support for IKEA Food Services goal development
Sustainability Manager	IKEA Industry	Responsible for IKEA Industry goal development
Project Engineer	IKEA Industry	Support for IKEA Industry goal development
Sustainability Manager	IKEA Transport	Responsible for IKEA Transport goal development
Sustainability Manager	IKEA Transport	Support for IKEA Transport goal development

The format of the focus group interviews mainly consisted of workshops due to the role as a supporting function in the climate target project. To plan the first focus group interview, it was constructed using the six-question guide suggested by Bader and Rossi (2002):

1. What is the reason behind the decision to use focus groups?
2. What is the general issue?

3. What are the specific issues?
4. What goals do you hope to meet using a focus group?
5. What purpose will the information serve?
6. From whom do you want to collect the information?

The workshops conducted during this master's thesis are summarised in Table 2.4. It includes the date of the workshop, attendants as well as the main area of discussion.

Table 2.4. The list of the held workshops during the research.

No.	Date	Attended by	Areas Discussed
1	6 March 2017	• Project Team	System Dynamics
2	2 May 2017	• Project Team	Production Drivers
3	3 May 2017	• Project Team • Specialist for emission quantification: agriculture & food	Food Ingredient Drivers
4	4 May 2017	• Project Team • Specialist for emission quantification: materials	Raw Material Drivers
5	5 May 2017	• Project Leader • Sustainability Leader Lightning • Product Development Engineer Appliances	Product Use Drivers

In addition to the focus group interviews, more formalised descriptions of emission drivers and steering parameters were collected at a later stage in the project. These requests were targeted at project stakeholders with specific knowledge in the different emission areas in the project.

The archival records collected consisted of computer files containing the data needed to quantify the GHG inventory. This data was initially collected in the different working units within the project. Specification of needed data for the simulation tool was requested from these units. Data for four emission areas were collected; raw material, food ingredients, production and product use.

2.5 Research Process

The research process resulted as an adaptation of the selected research approach, methodology, strategy and design. Using these components, the process could be broken down into six steps: (1) literature review, (2) problem introduction, (3) system investigation, (4) model formulation, (5) model construction and application, and (6) discussion and conclusion. The main activities for each process step are presented in Figure 2.5.

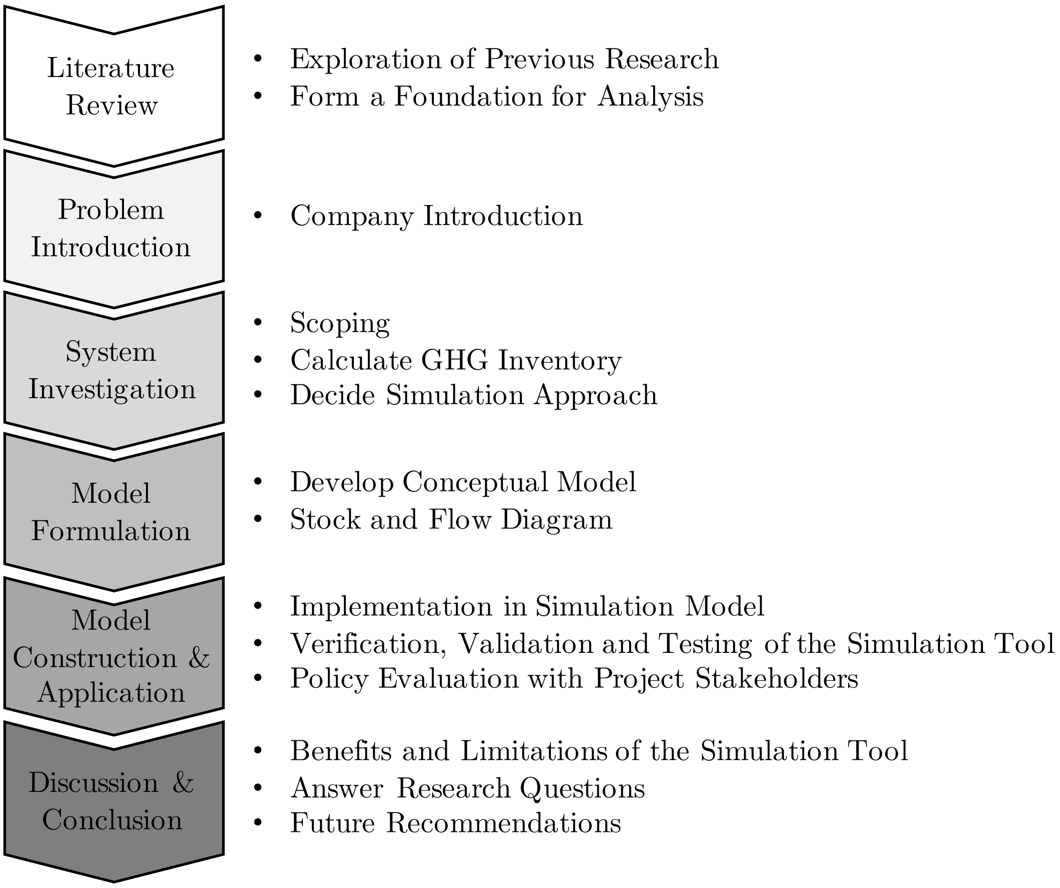


Figure 2.5. The research process with main activities in each process step.

2.5.1 Literature Review

A literature review was carried out as an initiation of the research to further comprehend the problem as well as to explore previous research in the area of simulation modelling, especially in the context of sustainability and value chain emissions. This involved research of areas including the SBT initiative, methods for setting climate targets, emission drivers in the value chain and simulation methodologies. The platform for doing so was journal articles, books and internet sources, including articles and reports from various initiatives and organisations. Search terms included:

- “science based targets” – this term was used to obtain a deeper understanding of the SBT initiative and the methodology for setting climate targets within the scope of the research.
- “supply chain emission” – this term was used to explore and identify emission drivers in supply (and value) chain from previous research. This was highly relevant when answering the first two research questions.
- “sustainability simulation” – to address the third research question, a broad search term was used to explore which simulation approaches that has been applied in previous research in the context of sustainability.

2.5.2 Problem Introduction

An introduction to the company and the project was held by involved stakeholders. During this time, alignment with the time plan of the project and the master's thesis was carried out to assure completion within the time frame set out for the two parts. A clear definition of the role in the project was stated and communicated to all stakeholders.

2.5.3 System Investigation

The initial approach for investigating the Scope 3 system was to first and foremost assist the company in scoping the project. This was done by mapping the value chain activities to achieve transparency and consensus among all involved stakeholders, including external representatives of the SBT. Together with stakeholders from all project units, a draft of the scope structure was created to determine the level of detail. Part of the process also consisted of supporting the different emission areas to quantify the GHG inventory for the project. This also gave an initial perception of what data and additional information that needed to be collected for the simulation tool.

As further understanding of the Scope 3 system was gained, the different simulation approaches identified from the literature review was investigated to evaluate their applicability for the research. This process step was crucial when adapting a suitable simulation approach and designing the simulation tool.

2.5.4 Model Formulation

When understanding of the Scope 3 emissions system was achieved, a conceptual model could be developed. Initial perceptions of interrelationships between the system elements in the value chain were formulated using contributions from stakeholders in the project. Future emission trends and trajectories were also addressed to stimulate additional input for potential steering parameters that may be used for policy formulation. The outcomes of this process step served as an initial foundation when answering the first two research questions.

Partly derived from the conceptual model and system elements, the methodology for setting climate targets in the project could be documented. Using this information, a more detailed description of the data required for the simulation tool could be requested from the different emission areas.

2.5.5 Model Construction and Application

The development of the simulation tool commenced when a solution method had been presented, discussed and accepted by the project stakeholders. This was to assure that the simulation tool fulfilled the requirements and expectations for evaluating policies. Data collection was carried out as a parallel process to the model construction as new data became available.

Qualitative input from the model formulation phase was implemented in the simulation model by expressing them in quantitative equations, parameters and initial conditions. Emission drivers and steering parameters were modelled in consensus with targeted stakeholders with good system knowledge of specific emission areas. Additional verification, validation and testing of the simulation tool were carried out continuously throughout the model construction phase. Stakeholders with deeper knowledge within specific areas of the actual emission system were utilised to validate the sanity and certainty of the simulation tool results.

When a satisfactory level of validation of the simulation model was achieved, policy evaluation was performed using scenarios and policies formulated by the different working units in the project.

2.5.6 Discussion and Conclusion

Analysis and evaluation of the simulation tool were conducted by discussing the benefits and limitations of the tool. Recommendations for further improvements of the simulation tool was also addressed. Lastly, reconnection to the initial research questions was held when drawing conclusions from the research.

2.6 Research Credibility

There are multiple criteria to assess the credibility of field research (Gibbert et al., 2008). Construct validity, internal validity, external validity, and reliability are four tests that are widely used to assure the quality in case studies (Yin, 2009).

2.6.1 Construct Validity

Construct validity refers to the procedure of identifying operational sets of measures which assure that research reflects the studied phenomena (Yin, 2009). This test is important to consider during the data collection phase to assure that the research investigates what it claims to investigate (Gibbert et al., 2008). Yin (2009) proclaims three tactics to apply in order to increase construct validity when doing case studies. The first one consists of using multiple sources of evidence, a form of triangulation where the researcher adopts different angles to study the phenomenon. The second is to establish a clear chain of evidence that connects the specific concepts with the initial research question. The third is to have key informants to review a draft of the case study report (ibid).

2.6.2 Internal Validity

Internal validity applies mainly for explanatory case studies and not for descriptive or exploratory research (Yin, 2009). It refers to accurately mapping the causal relationships between events and factors. These must be thoroughly mapped to conclude that other factors do not have an influence on the causal relationship. The tactics for doing so involves pattern matching, explanation building, address rival explanations and use logic models (ibid).

2.6.3 External Validity

The third test consists of external validity and implies that the findings of the research go beyond the immediate case study, meaning that they should be generalizable (Yin, 2009). Case studies rely on analytical generalisation, in difference to survey research which relies on statistical generalisation and strives to transform the outcome of a specific set of results into broader theory. To address this, external validity is targeted towards the research design. For single case studies is alignment with theory important to enhance the external validity whereas replication logic may be applied in multiple-case studies (ibid).

2.6.4 Reliability

Reliability in the context of research refers to minimising the errors and biases in the study, enabling other researchers to conduct the same research procedure and achieve the same conclusions (Gibbert et al., 2008; Yin, 2009). This aspect of credibility is especially important to consider during data collection. For subsequent researchers to achieve replicable results, the procedures of the earlier study must be documented (ibid). Yin (2009) suggests two tactics for doing so; (1) use case study protocol, and (2) develop case study database. A case study protocol is a report that specifies how the research has been conducted. A case study database refers to all the documentation that have acquired during the research, arranged in a manner that facilitates replication of the study (ibid).

2.6.5 Credibility in this Research

Construct validity is ensured in this research by addressing all three tactics suggested by Yin (2009). By relying on both previous research as well as focus group interviews when identifying the emission drivers in the Scope 3 system, multiple sources of evidence could be compared and validated. A clear chain of evidence was ensured by clearly motivating the selected methodology for the research. Furthermore, discussion of the assumptions and delimitations of the simulation tool is presented to increase the transparency of the conclusions. Having key informants reviewing the case study was achieved by continuous verification, validation and testing of the simulation tool by project stakeholders.

Internal validity was considered when answering the first two research questions. Causal relationships within the Scope 3 system was thoroughly mapped when identifying the emission drivers. Pattern matching was applied when comparing the qualitative contribution from focus group interviews with the theory identified during the literature review.

A limitation of the external validity of this research is that a single case study delimits the generalizability. However, by clearly stating and describing the case study selection and context, the analytical generalizability is enhanced.

In order to facilitate succeeding research to reproduce the findings in this case study, the research methodology is formulated with the aim of being as transparent as possible. Additionally, the empirical data is presented to capture sufficient level of detail to replicate the study in other contexts and settings. All assumptions are clearly stated and motivated to allow for critical review.

2.7 Summary of Methodology

A summary of the selected methodology for this research is presented in Figure 2.6.

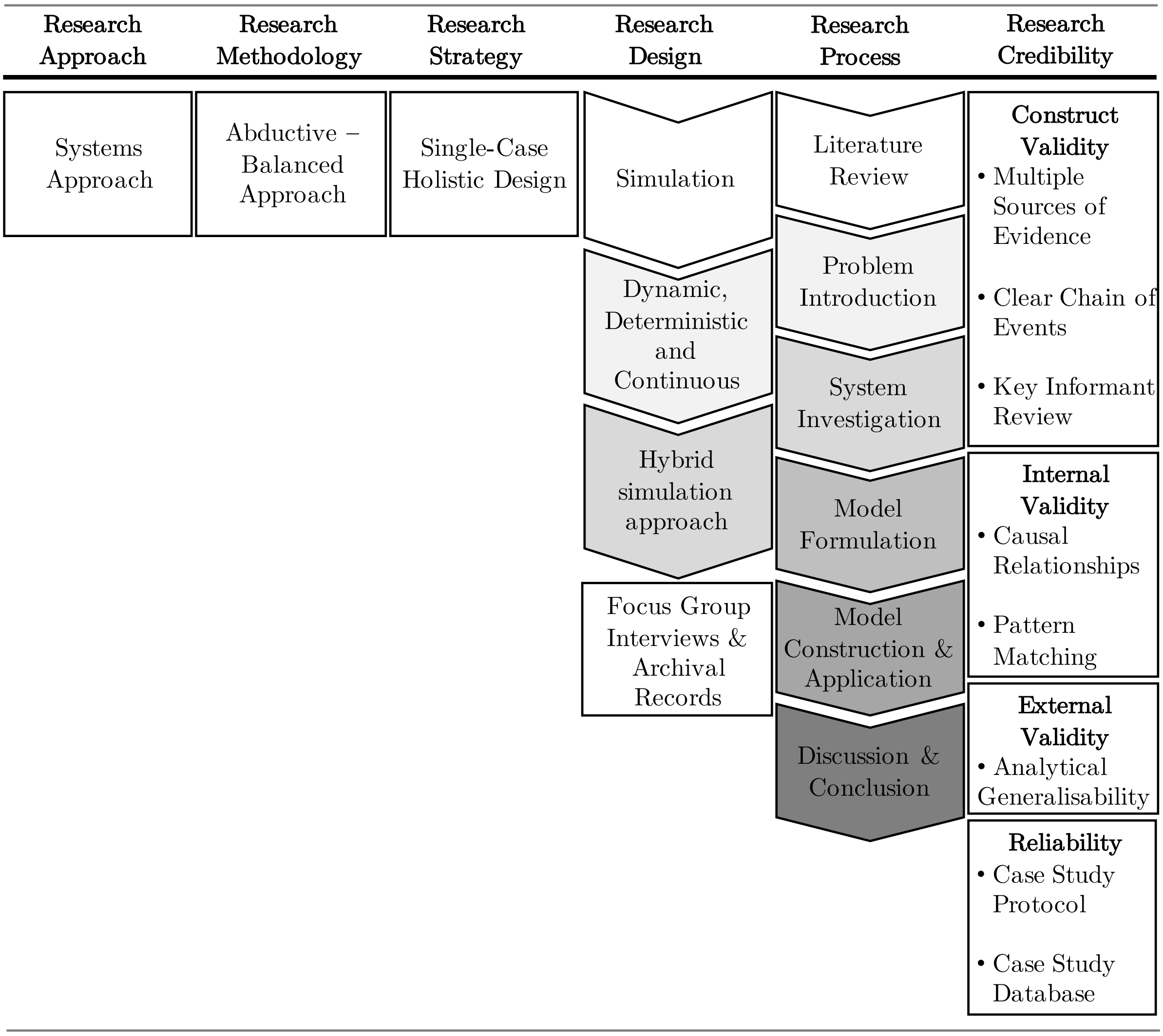


Figure 2.6. Summary of selected methodology of this research.

3 Frame of References

This chapter presents the theoretical frame of reference that has been considered for this research. The objective is to provide an adequate background of the subjects of study in order to enhance the understanding of the findings in the analysis and conclusion.

In order to successfully answering the research questions, three areas of interest were identified during the initial literature review; Science-based Targets, Value Chain GHG Emissions, and the System Dynamics Modelling Process. In combination, these areas served as the theoretical foundation when designing the simulation tool, see Figure 3.1. Theory regarding SBT provides helpful methods and calculation guidance on how to calculate a company's GHG inventory. Literature regarding GHG emission drivers was studied to find applicable drivers to implement and steer in the simulation tool. Lastly, the underlying theory for the system dynamics modelling process is presented to describe the methodology that was applied when developing the simulation tool.

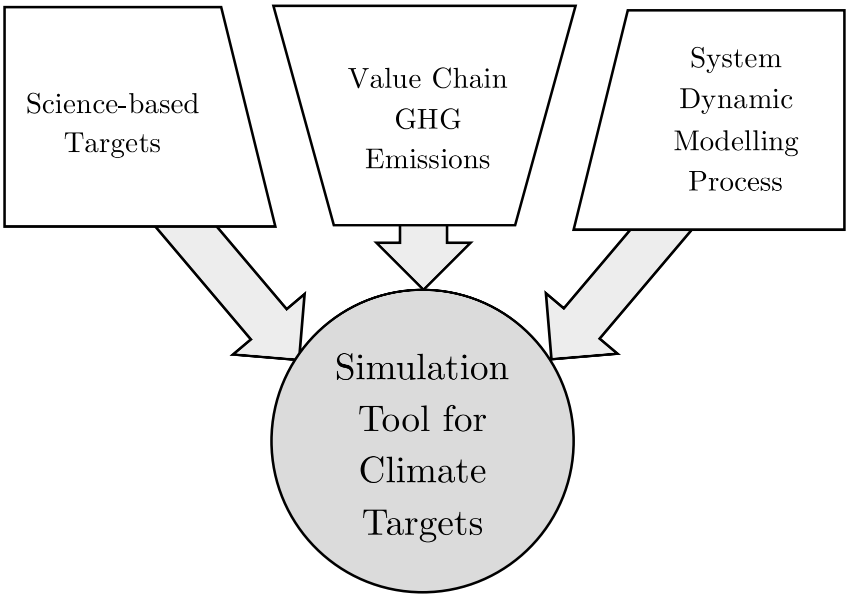


Figure 3.1. The three theoretical areas of interest for the simulation tool.

3.1 Science-Based Target Initiative

3.1.1 Background

The Intergovernmental Panel on Climate Change (IPCC) states in the "Fifth Assessment Report (AR5)" (IPCC, 2014) that, even with latest mitigation attempts for GHG emissions, total anthropogenic GHG emissions continued to grow between 2000 and 2010. GHGs contributing to direct emissions related to human activity are carbon dioxide (CO_2), methane

(CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). Combustion of fossil fuels in energy conversions systems, e.g. electric power plant boilers, automobiles and cooking and heating at home or at business, accounts for the majority of CO_2 emitted. About one-third comes from agriculture (mainly N_2O and CH_4), deforestation (mainly CO_2), industrial processes (mainly N_2O, CO_2 and fluorinated gases (F-gases)) and the production of fossil fuels (mainly CH_4) (ibid).

The world's governments agreed in 2010 to work towards a limit of two-degree warming which is deemed enough to avoid the worst effect of climate change (CDP, 2015). In December 2015, a new global agreement was adopted under United Nations Framework Convention on Climate Change (UNFCCC) in the form of the Paris Agreement. The objective of the agreement aims at holding global warming to well below 2°C and to "pursue efforts" to limit it to 1,5°C (Rogelj et al., 2016). This entails a carbon budget, i.e. the threshold of how much carbon that can be emitted, of 1,180 Gt CO_2. Said carbon budget allow a higher than 66 percent chance of meeting the 2°C target, henceforth called the 2°C scenario (2DS). Meeting the 2DS would require a 41-72 percent reduction of global emissions by 2050 (CDP, 2015).

The International Energy Agency (IEA) has modelled another 2°C and 6°C scenario on a sector-by-sector basis to display the gaps between 2013 to the year 2050 (CDP, 2015).

- This 2°C scenario (IEA 2DS) entails that almost 60 percent of CO_2 emissions are reduced by 2050 (IEA, 2017). This scenario allows for higher than 50 percent chance of limiting global warming to 2°C (ibid).
- The 6°C scenario (IEA 6DS) is largely based on current trends. Without any means of limitation, CO_2 emissions are projected to rise by about 60 percent between 2013 and 2050 (IEA, 2017).

The modelling accounts for cost-effectiveness and mitigation options on every sector (CDP, 2015). These huge reduction requirements, as can be seen in Figure 3.2, will be impossible for companies to achieve without reforming their business models and energy procurement and use (ibid).

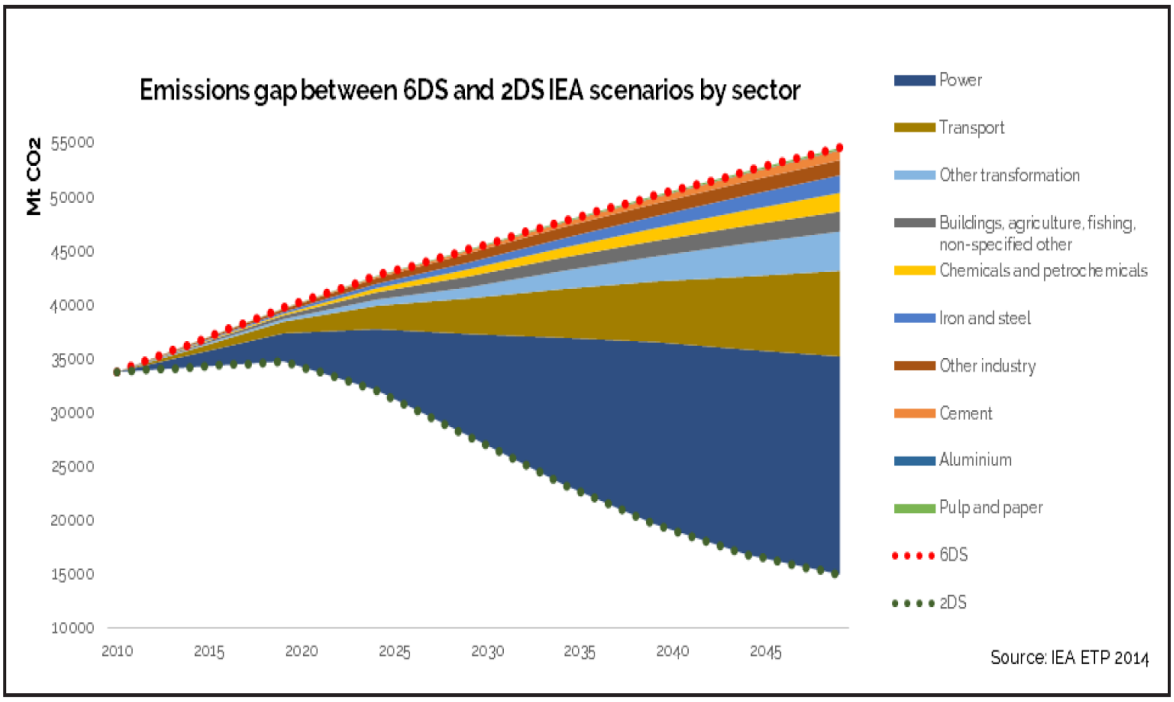


Figure 3.2. IEA modelling of emission gaps between IEA 2DS and IEA 6DS (CDP, 2015, p.4).

3.1.2 The Initiative

The Science-based Target initiative (SBTi) helps and urges companies to develop emission reduction targets (SBTi, 2015). For a target to be science-based, decarbonisation is required to keep global temperature below 2°C increase compared to pre-industrial temperatures, i.e. following the world's government's 2DS. The initiative is a collaboration between WRI, UN Global Compact, CDP and WWF. There are three scopes within the initiative, see Figure 1.3 in Section 1.6 Focus and Delimitations. Assessing GHG inventories and targets on Scope 1 and 2 is mandatory to get the SBTi certification. GHG inventory of Scope 3 is only mandatory if the company projects Scope 3 emissions to be over 40 percent of total emissions (ibid).

A SBT comprises three elements; carbon budget, emission scenario, and allocation approach (SBTi, 2015). The world's governments' carbon budget is included in all SBTs. Emission scenarios are actions and pledges already in place that attempts to lower global warming. Allocation approach combines the carbon budget and emission scenario to allocate decarbonisation requirements among companies. There are two methods for allocation; convergence, where all companies within a specified sector are required to reduce their intensity metrics to a common value depending on the sector's growth rate and initial carbon intensity. The second method is contraction, where all companies, regardless of their sector, reduce either their intensity metrics or absolute emissions. However, if a company operates in more than one sector, the top contributing sectors to total emissions should be identified.

Including offsetting, i.e. discrete GHG reduction applied to compensate for emissions occurring elsewhere, is not allowed when setting a SBT (ibid).

3.1.3 Modelling Scope 3 Targets

When setting SBTs, most companies focus on Scope 1 and 2 emissions since it is often easier to influence GHG emissions in these scopes (SBTi, 2015). Scope 3 emissions, however, often turns out to be much greater than Scope 1 and 2 combined and could prove to be crucial to reach the required level of decarbonisation. A company starts by first assessing whether an ambitious Scope 3 target should be set or not. If Scope 3 emissions account for over 40 percent of total emissions of the baseline year chosen, an ambitious Scope 3 target should be set. It is then up to the company to assess which source categories to target (ibid).

The Greenhouse Gas Protocol (GHG Protocol) is the most widely applied accounting tool to quantify, understand, and manage GHG inventory (GHG Protocol, 2017). It is a decade-long partnership between World Business Council for Sustainable Development (WBCSD) and WRI and serves as a foundation for a vast amount of GHG standards in the world (ibid). The GHG Protocol (GHG Protocol, 2011; GHG Protocol, 2013) provides helpful methods and calculations to assess Scope 3 emissions. The two emission source categories that are of interest for this research, as presented in Section 1.6 Focus and Delimitations, are (1) Purchased goods and services, and (2) Use of sold products.

Purchased Goods and Services

This category handles all upstream cradle-to-gate emissions from produced goods that are purchased or acquired by the reporting company during the baseline year (GHG Protocol, 2011). Products that are not tangible, e.g. services, should also be included here. All emissions that occur from raw material (cradle) to the reporting company (gate) is to be handled meaning a lifecycle analysis (LCA) is needed (ibid). Cradle-to-gate emissions can involve:

- Raw material extraction
- Agricultural activities
- Production, processing and manufacturing
- Generation of electricity
- Treatment/disposal of waste generated
- Land-use
- Internal transport

The GHG Protocol (2013) presents a decision tree to decide between four different calculation methods available to calculate the GHG emissions for this category. The decision tree can be seen in Figure 3.3.

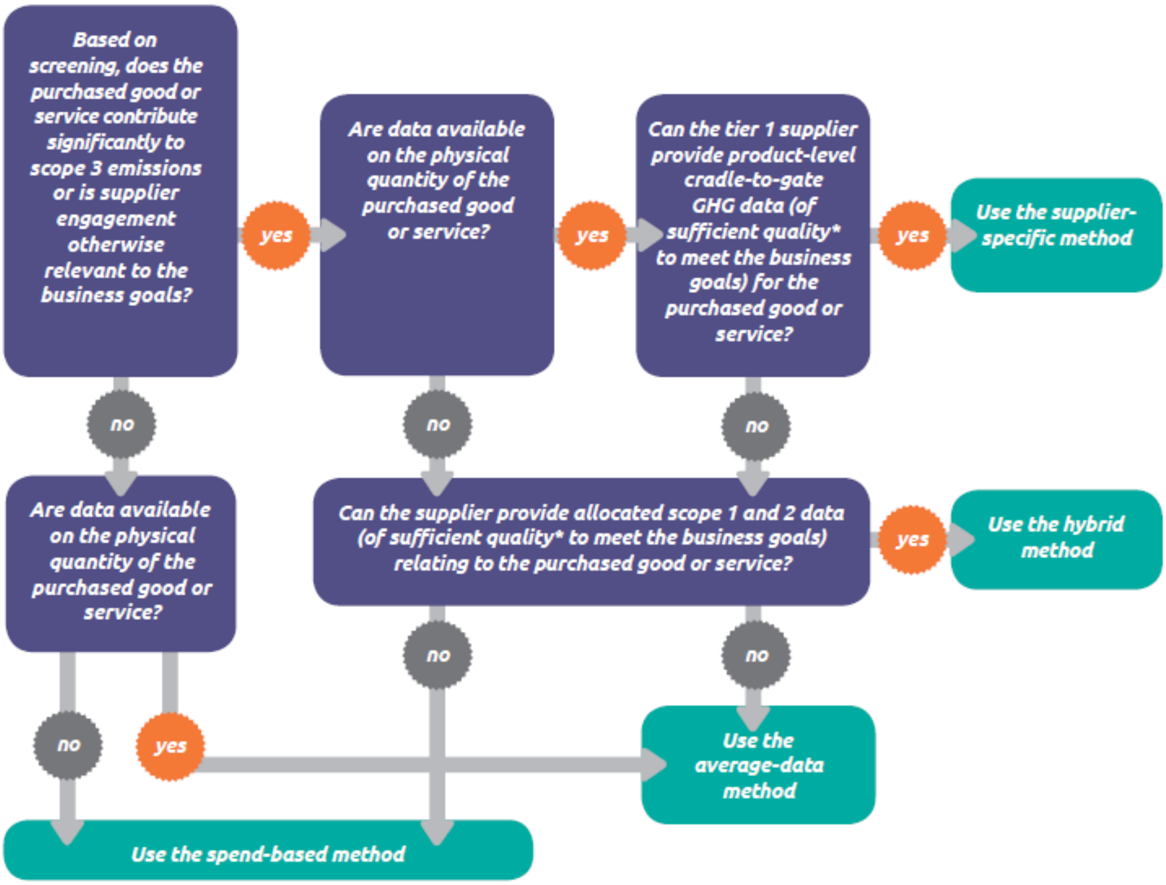


Figure 3.3. Decision tree for selecting a calculation method for category 1 (GHG Protocol, 2013, p.23).

The four calculations methods are; Supplier-specific method which is when the company collects cradle-to-gate GHG inventory data from all suppliers to assess product-level emissions (GHG Protocol, 2013). The hybrid method which can be applied if the company is unable to acquire supplier-specific data from all suppliers and wish to fill the gaps with average-data methods. Average-data method is when the reporting company estimates emissions by collecting mass or quantity data and apply an industry average emission factor. Lastly, the spend-based method is similar to average-data method but uses economic values of products purchased rather than the mass or quantity. An industry average emission factor is then applied based on the economic value. An important factor when deciding upon a calculation method is to consider the granularity of the data required. The supplier-specific method and hybrid method does not have to be more accurate than average-data or spend-based if the supplier data provided is faulty (ibid).

Use of Sold Products

All emissions related to product use is included in this category (GHG Protocol, 2011). Calculations should be based on all products that have direct use-phase emissions, e.g. fuel consumption. Indirect use-phase emissions, e.g. refrigerant leakage, should be included if deemed significant.

The reporting company are to multiply use-phase emissions with their corresponding lifetime. In order to avoid penalisation of companies who produce durable products and to avoid misinterpretation of data, companies can report lifetime and intensity metrics such as emission per hour of use. The reporting company is allowed to estimate the use-phase emissions themselves without interacting with or questioning the customers. This typically requires assumptions about consumer behaviour and product design specifications (ibid).

3.2 Value Chain GHG Emissions

There is a wide variety of GHGs that contribute to global warming, therefore emission metrics exchange rates exist to make it more comprehensible. These exchange rates also serve as a way to apportioning mitigation effects and aggregating total emissions. GHGs differs in physical characteristics, e.g. CH_4 stays in the atmosphere for a shorter time period than CO_2 but causes a stronger instantaneous radiative force. Thus, both time horizon and the radiative force needs to be quantified to find the relative contribution. An example of such a metric is Global Warming Potential (GWP). GWP is used to quantify the effect of a GHG into a common scale, i.e. CO_2 equivalents (CO_2 eq) (IPCC, 2014).

In 2013, the highly energy intensive industrial processes accounted for one-third of global energy use (Napp et al., 2014). Around 70 percent of the energy use originates from fossil fuels which entail that said processes account for 40 percent of the global CO_2 emissions. By maintaining business as usual (BAU), i.e. not enforcing decarbonisation, projections show an increase of emissions of 74-91 percent by 2050 (ibid). The industrial process of a product is not the only activity emitting CO_2 eq (Boone et al., 2012). Throughout the lifecycle, a product's CO_2 eqs are emitted right from extraction and transformation of raw materials, manufacturing and production of the product, the use of the product and at the end-of-life. However, reporting said emissions for a product or service is a quite recent phenomenon (ibid).

3.2.1 Emissions Occurring during a Product's Lifetime

When assessing product footprints, the product is often chosen based on the goal of the project (Boone et al., 2012). Market opportunities, cost savings, and potential time and efforts needed are factors typically considered. There are several methodologies available to assess GHG emissions, e.g. ISO14040, ISO14064 and previously mentioned GHG Protocol (ibid). A typical lifecycle can be seen in Table 3.1. As mentioned in Section 1.6 Focus and Delimitations, this thesis is delimitated to certain life-cycle stages.

Table 3.1. Activities typically involved in lifecycle assessment (Boone et al., 2012, p.181).

Life-cycle stage	Sample Activities	Examples
Raw Materials	Impact of raw materials	Deforestation, etc.
		Land use change
	Inputs used in the products	Bill of materials or teardown reports
	Typical processes	Extraction/mining
		Farming
		Livestock
		Logging
		Processing
		Transportation
		Waste streams
Manufacture	Inbound logistics	Processing
		Shipment of raw materials to manufacturer/assembly
		Storage
	Outbound logistics	Packaging
		Storage
	Production processes	Facilities
		Inputs and outputs of production
		Intermediate and final products produced
		Waste streams generated
Distribution/ retail	Distribution operations	Processing
		Shipment to distribution center
		Storage
	Retail operations	Display
		Processing
		Shipment to retail/customer
		Storage/refrigeration
Consumer use	Use	Maintenance
		Repair
		Use of products
End of life	Waste streams	Composting
		Landfilling
		Recycling
		Take back/remanufacturing, etc.
Other considerations	Capital goods	Any capital to enable lifecycle activities
	Employees	Business travel
		Commuting
	Facilities	Franchises
		Leased and owned assets

The life-cycle stages of interest for this research includes; (1) Raw material, (2) Manufacture, and (3) Consumer use and will be further addressed in Section 3.2.3 GHG Emission Drivers in Value Chain Activities.

3.2.2 Data Collection

When collecting data to assess the GHG inventory, there are typically two different methods (Boone et al., 2012); (1) activity data, which is the type and quantity of inputs and outputs, e.g. net GHG emission, and (2) emission data, which is standard factors typically provided by industry-specific databases. CO_2 eq measures are usually applied on emission data. There are numerous ways on how to collect activity data. Direct measurements and industry estimate are two common approaches. Direct measurements refer to collecting supplier-specific data directly from the supplier base, whereas industry estimate can be used if supplier-specific data is hard to acquire. For smaller suppliers, which might not assess GHG inventory, secondary data from well-established lifecycle databases might be available and can be used. The goal is to have a consistent, accurate and repeatable protocol of data collected in order to enhance tracking and allocation of GHG emissions to the right source or activity (ibid).

3.2.3 GHG Emission Drivers in Value Chain Activities

When the total GHG footprint is calculated, it can be used to identify "hot spots" of carbon emitted during a product's lifecycle, thus, telling the company on which area to focus on (Boone et al., 2012). Boone et al. (2012) present a list of possible mitigation options to reduce GHG emissions, the table has been adapted to fit the project scope, see Table 3.2. For this research, a distinction will be made between industrial raw material, e.g. metals, minerals and plastics, and agricultural raw materials, e.g. forestry and food ingredients.

Table 3.2. Examples of mitigation options for the different value chain activities (Adapted from Boone et al., 2012, p.184).

Category	**Example of action steps**
Material input	Use less quantity
	Use materials which can be reclaimed
	Use materials which can be "upcycled"
	Sustainable extraction (seafood, logging, mining, etc.)
Energy Use	Increase share of renewable energy
	Use efficient fuels
	Reduce energy consumption
Production processes	Increase efficiency in process
Consumer use	Design for energy efficient use

3.2.3.1 Industrial Raw Material and Production

It is increasingly recognised that a deep decarbonisation in the energy intensive raw material (basic material) industry is required in order for the European Union (EU) to reach the agreed upon 2DS (Lechtenböhmer et al., 2016). The production of basic materials such as cement, glass, steel, petrochemicals, chlorine, lime and ammonia contributed to 9 percent of EU28's total GHG emissions (ibid).

Lechtenböhmer et al. (2016) state three technical options that are viable for reducing emissions related to raw materials and production. These are (1) improved efficiency of materials, (2) improved energy efficiency of production and, (3) reducing the carbon insensitivity of the energy supply. Improving efficiency of materials can be done by increasing the use of recycled materials and by applying lightweight technologies, i.e. using less material but maintaining same functionality. This would decrease the need for the energy intensive process of transforming ores and minerals to ingots. Furthermore, an extension of product lifetime and maintaining product designs that allow for easier maintenance, repair and remanufacturing would further decrease global raw material demand. This is a central point of circular economy. However, even if circular economy is achieved, the need for virgin materials will never cease to exist as the quality of recycled material is lower. Thus, virgin material will have to replenish the system at some point (ibid).

In order to achieve the deep carbonisation required, only improving the efficiency of material will, however, be insufficient (Lechtenböhmer et al., 2016). It is also necessary to look at the feedstock processing of raw material to usable material and products, i.e. the process-related emissions. A huge reduction can be achieved by shifting to low-carbon energy sources, e.g. nuclear energy, biomass and renewable electricity. Carbon capture and storage (CCS) and bioenergy are the two main options assessed, as of today, to reduce emissions of energy intensive industries. For the industries of cement, chemicals, steel, pulp and paper, CCS is the most viable solution to achieve a decarbonisation of 70-90 percent (ibid).

Lechtenböhmer et al. (2016) assess future scenarios of decarbonising materials and production processes. Examples are; to induce electrolysis technique when extracting useable material out of iron ore, thus reducing the use of chemicals and using electric furnaces to melt glass instead of natural gas which is used today. It is, however, uncertain if electrical furnaces will be able to perform as well as natural gas for all qualities of glass. Apart from CCS, electrification of processes with renewable energy and shifting to biomass are the most valid options for a deep decarbonisation. Both CCS and biomass are, however, widely discussed, CCS has two camps where one recognises huge potential whereas the other is sceptic and biomass might have very limited resources in the future. Renewable electricity is, therefore, the energy source with the least resource limitations and negative impacts for the future. A comparison of year 2010 and 2050 can be seen in Figure 3.4 where the difference between the flow of CO_2 (grey flow) is key. The result shows that a major reduction of emissions from basic materials is feasible (ibid).

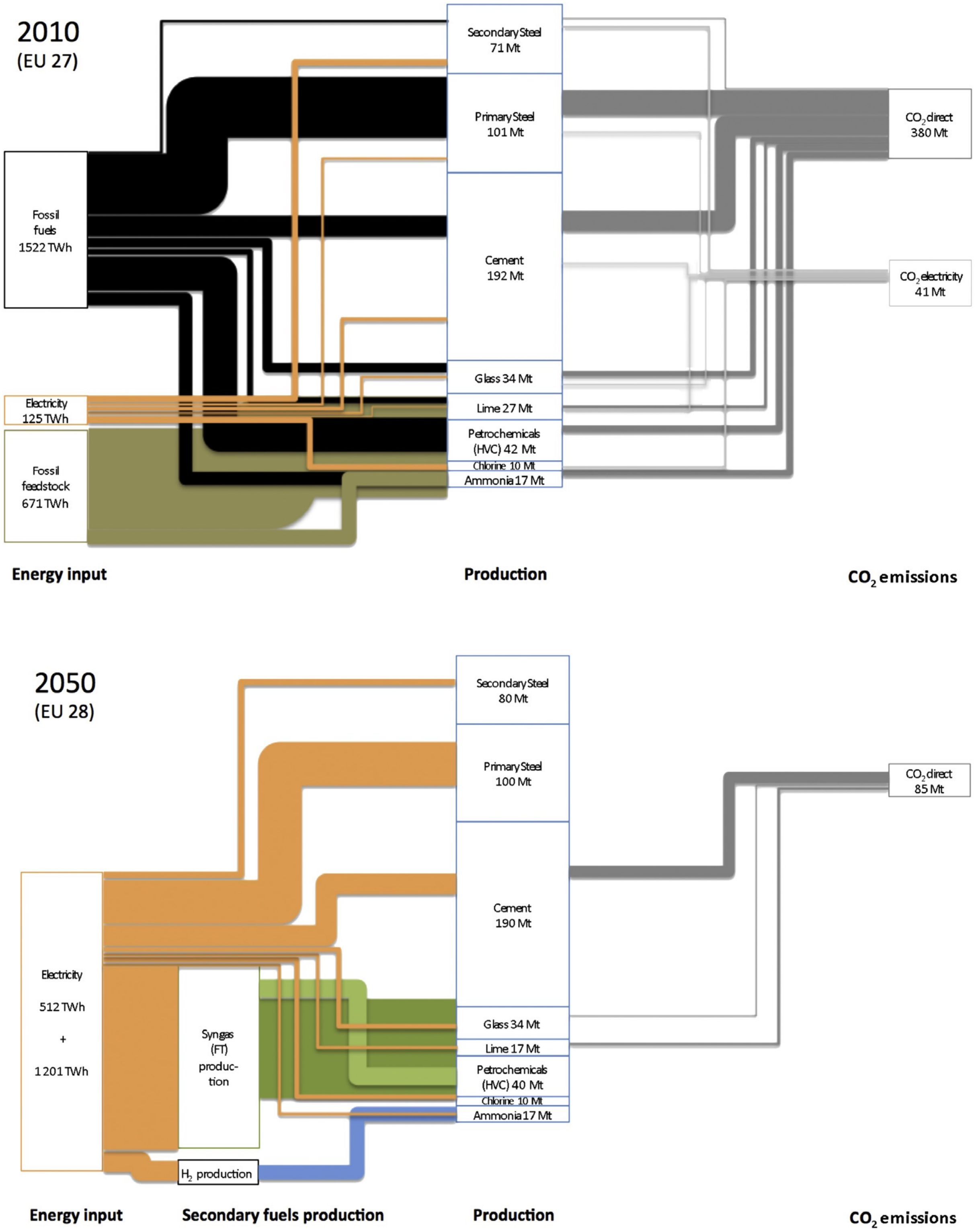


Figure 3.4. A scenario comparison of eight basic materials at year 2010 and 2050 (Lechtenböhmer et al., 2016, p.7).

Whilst the above actions are promising to decarbonise production and the raw material industry, Napp et al. (2014) proclaim that in order to reach a net-zero decarbonisation it is hard, if not impossible, without taking a lifecycle and system-based approach. Kuo et al. (2014) stress the importance of making an impact early on in the lifecycle by providing the developing team with raw material footprints. Both resource efficiency and sufficiency are highlighted as complimentary approaches for sustainable manufacturing (Napp et al., 2014). In resource sufficiency, reducing the demand for a product is key whilst in resource efficiency, producing products with less material without losing the functionality or quality is key. Furthermore, recycled and renewable plastics and metals are of key importance for energy savings. Recycled steel is around 40 percent more energy efficient than virgin steel while recycled aluminium can be up to 20 times more energy efficient than virgin aluminium. Bio-plastics, i.e. renewable plastics, can potentially substitute 90 percent of global plastic and fibre consumption. However, renewable plastics often entails higher cost and lesser quality (ibid).

Emissions from refrigerant leakage is also an important factor to take into account (Koronaki et al., 2012). All refrigeration systems have a risk of leaking as the pressure in said system are higher than the atmosphere. The leaking of refrigerant does not only cause direct emission, i.e. refrigerants released into the atmosphere, but also indirect emissions since leakage of refrigerants increases power consumption. This is due to a decrease of energy efficiency in the refrigeration systems. Natural refrigerants such as e.g. propane R290 and propylene R1270 has a very low GWP compared to HFCs (ibid).

3.2.3.2 Agricultural Raw Material and Production

Forestry

Depending on the wood products life length and type it will act as a carbon reservoir which delays the emission of sequestered carbon back into the atmosphere (Saud et al., 2015). Bergman et al. (2014) suggest that the carbon stored in northeastern US lumber production is approximately double of total carbon emitted from the very same industry, this is called carbon offsetting. At the end of life, wood products can act as biomass feedstock, thus providing energy for other processes. Furthermore, wood can be recycled into new engineered products or reused in new constructions. When, for example, wood is reused in new softwood framing lumber constructions, there are about one-fourth less fossil CO_2 emitted than with virgin wood products. Wood product production is also a less energy intensive process than many other industrial processes. This contributes to the fact that wood has many environmental advantages over other materials such as plastics, concrete and metals (ibid).

The advantage of wood-based products is important and might be obvious for many, however, not everyone recognises and understands the potential (Bergman et al., 2014). As with most other raw materials, LCA is used to fully understand the emissions related to forestry. A common finding during LCAs shows that the manufacturing process accounts for at least 10 times higher emission than forest removal and transportation (ibid).

It is, however, important to know that the yield of a cut-down tree is not always 100 percent (Sathre and Gustavsson, 2011). Logging residues, i.e. bark, branches and tops, which accounts for about 30 to 50 percent of the harvested tree are not always collected but still included in the raw material emission factor. Instead, it is left on the ground to decay when it could have been used further down the value chain to fuel other processes such as saw-mills. Therefore, in order to reach the full potential of decarbonising forestry, forest management programs should include a collection of logging residues (ibid).

Food Ingredients

All the way from the farming process through to production, distribution, storing and food preparation, GHGs are produced (Garnett, 2011). During the farm stage, N_2O from livestock processes and soil, and CH_4 from anaerobic soils and ruminant digestions are the dominant GHGs. CO_2 emissions, from power machinery and combustion of fossil fuels, also contributes to a lesser extent. However, if land use change, e.g. through deforestation, CO_2 emissions can add considerably to farm-stage impacts. Beyond the farm stage, CO_2 emissions are the dominant GHG for all other activities in the food supply chain where the majority of these CO_2 emissions comes from the combustion of fossil fuels and the use of refrigerants. Figure 3.5 shows the breakdown of all GHGs occurring up to and beyond the farm gate, the proportions are, however, for an illustrative purpose (ibid).

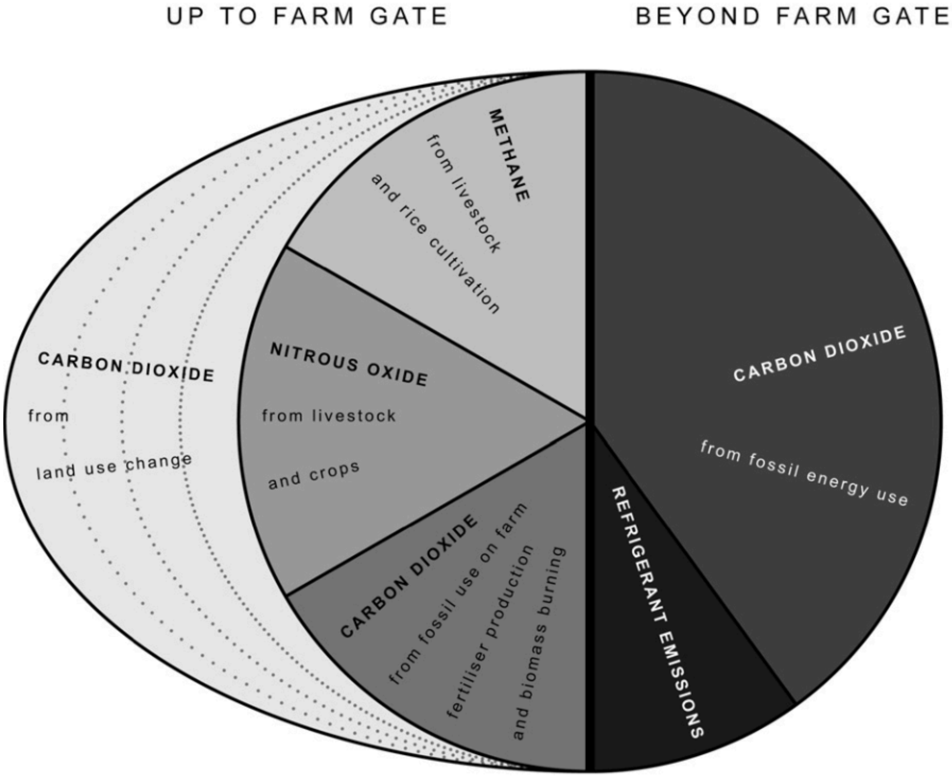


Figure 3.5. Breakdown of GHGs occurring in a Food Supply Chain (Garnett, 2011, p.S24).

In order to fully grasp the breakdown of GHG emissions in a food supply chain, a full LCA is required (Garnett, 2011). It is not feasible to benchmark with other companies as food emission estimates will vary based on used methodology, boundary placement, location, assumptions, land use, fuels used and quality of the data. However, a general finding is that meat, dairy and food transported by air accounts for the highest GHG emissions (ibid). IPCC (2014) provides a comparision showing GHG emission intensities of various food ingredients in relation to roundwood which can be seen in Figure 3.6.

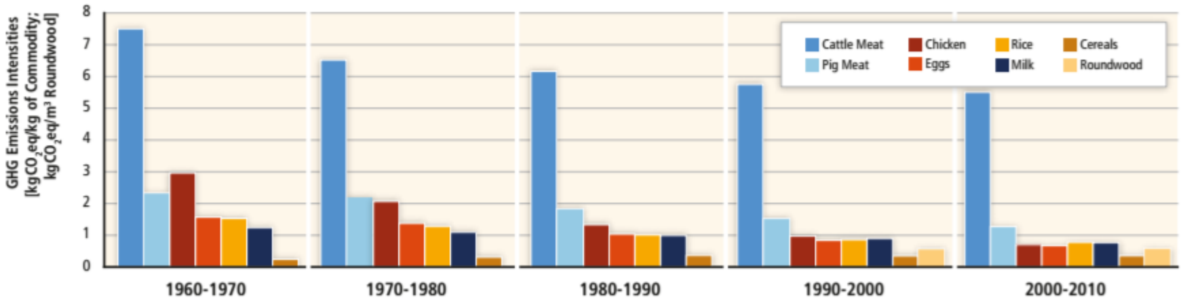


Figure 3.6. Assessment of various food ingredients GHG emissions compared to roundwood (IPCC, 2014, p.87).

There is extensive literature available on how and why the world needs to reduce GHG emissions from the food supply chain. Garnett (2011) broadly summarises five categories on how to reduce pre-production emissions:

1. **Enhancing carbon removals** – More sustainable raw material extractions by reducing deforestation and minimise or eliminate tillage.
2. **Optimising nutrient use** – Using a precise dosage of fertilisers.
3. **Improving productivity** – Increasing the edible output of an ingredient compared to its emission factor by e.g. increasing the yield, both at farm and production level, or finding methods to reduce the emission factor.
4. **Managing and benefiting from the outputs** – Waste composting, using manure and plant biomass.
5. **Reducing carbon intensity of fuels** – This can be done by introducing more eco-friendly fuels at the farm.

Furthermore, Garnett (2011) discuss the importance of changing the global food consumption behaviour. Meat, as previously mentioned, has generally a higher emission factor than vegetables. By changing the food consumption behaviour towards a vegetarian diet, the GHG emissions would decrease. Another important factor is to reduce both pre- and post-consumer waste. Pre-consumer waste is all food waste generated before the consumer and post-consumer waste is all food waste generated by the consumer. Scenarios to reduce food emissions from consumption behaviour can be seen in Table 3.3 (ibid).

Table 3.3. Scenarios to reduce emissions from consumption behaviour (Garnett, 2011, p.S30).

Priority	Action	Impact Area Addressed	Problems
High	Eat fewer meat and dairy products	N_2O and CH_4 emissions; lost carbon sequestration from possible land clearance overseas; fossil fuel use	Reductions in both UK production and imports will be needed or else the problem will be shifted overseas; risk that fish takes the place of meat in people's diets, so increasing pressure on fish stocks
High	Eat no more than needed to maintain a healthy body weight	Eating more food than needed stimulates the production of more food than is needed, and hence GHG emissions	Risk that individual people are victimised; overconsumption of food needs to be situated within an overall approach to consumption and consumerism
Medium, possibly high	Do not waste food and manage unavoidable waste properly	Less food waste permits lower levels of food production	The waste issue raises structural, system questions that are linked to the whole consuming less debate
Medium	Eat seasonal, robust, field grown vegetables rather than protected, fragile foods prone to spoilage and requiring heating and lighting in their cultivation, refrigeration, and rapid modes of transport	Tackles areas of refrigeration, transport, food spoilage	Measures to reduce air-freighted foods may clash with international development objectives
Medium	Prepare food for more than one person and for several days	Efficiencies of scale – reduced energy use	Requires a measure of pre-planning. Trends in how people actually live and average household size make this approach difficult
Medium	Accept different notions of quality	Less waste permitting lower levels of production	Food that is edible but deemed of lower quality or undesirable goes to food processing or animal feed, or can go for export, so it may not always actually be wasted

Priority	**Action**	**Impact Area Addressed**	**Problems**
Medium	Accept variability of supply	Tackles the problem of needing to supply foods even when the environmental cost of doing so is high	Variability within a complex food system may lead to bottlenecks and knock-on impacts which in turn can contribute to food waste; this approach may require a simpler food chain than the kind found in the developed world – one where foods are less processed
Medium	Consume fewer foods with low nutritional value, e.g. alcohol, tea, coffee, chocolate, bottled water	These ‘unnecessary’ foods are not needed in our diet and need not be produced	Raises major questions around free choice. Many of these foods (tea, coffee, chocolate) provide livelihoods to vast numbers of people in the developing world
Medium	Cook and store foods in energy conserving ways; possibly smart metering	Energy use in the home	Simple to do; saves money; impacts limited but useful
Lower	Shop on foot or over the internet	Reduced energy use	Research into the benefits of internet shopping is cautiously optimistic

3.2.3.3 Product Use

Once a product has been put on the market, there is nothing or relatively little a company can do to improve its sustainable characteristics (Ardente and Mathieux, 2014). This is an important fact to consider when developing new products. The company could, as Boone et al. (2012) presents in Table 3.2, design products for energy efficient use to reduce emissions.

When assessing the use of products, an underlying driver is the customer behaviour (IPCC, 2014). The behaviour of customers is, however, hard to delineate and attribute. Empirical evidence shows that consumption behaviour varies depending on region, seasons and social groups. Studies have also shown that customers often fail to choose appliances with higher energy efficiencies due to the higher capital cost. However, if the customers were to assess the potential energy savings they would, in many cases, see that said appliances often is the best from both economic and sustainable views (ibid). It is, however, hard for a company to influence consumer energy usage. Jackson (2005) found in his study that awareness creation or provision of information is unlikely to make a significant impact on consumer behaviour (ibid).

Another way to influence consumer energy consumption is to drive technological changes and innovations (IPCC, 2014). It exists adequate evidence that technological changes affect energy use and in Japan, it has proved to be a driver for mitigating CO_2 emissions. The energy sector plays a key role of this part and is the most widely studied area. A technological change in the energy sector could entail a change to the autonomous energy efficiency index, i.e. lowering energy intensity without increasing the costs (ibid).

3.3 System Dynamic Modelling Process

System dynamics is a set of conceptual tools which provides guidance on the structure and behaviour of complex systems by introducing feedback processes, stock and flow structures, nonlinearities and time delays to identify the dynamics (Sterman, 2000). System dynamics is also used as a rigorous modelling method to build formal computer systems which aid in designing more effective organisations and policies (ibid).

Modelling is inherently creative and modellers often create individual processes (Sterman, 2000). Constant iteration, testing, questioning and refinement will occur during the process. This project will follow a modelling process presented by Sterman (2000). The process includes the following steps; (1) Problem Articulation, (2) Dynamic Hypothesis, (3) Model Formulation, (4) Testing and (5) Policy Formulation and Evaluation (ibid). The modelling process can be seen in Figure 3.7.

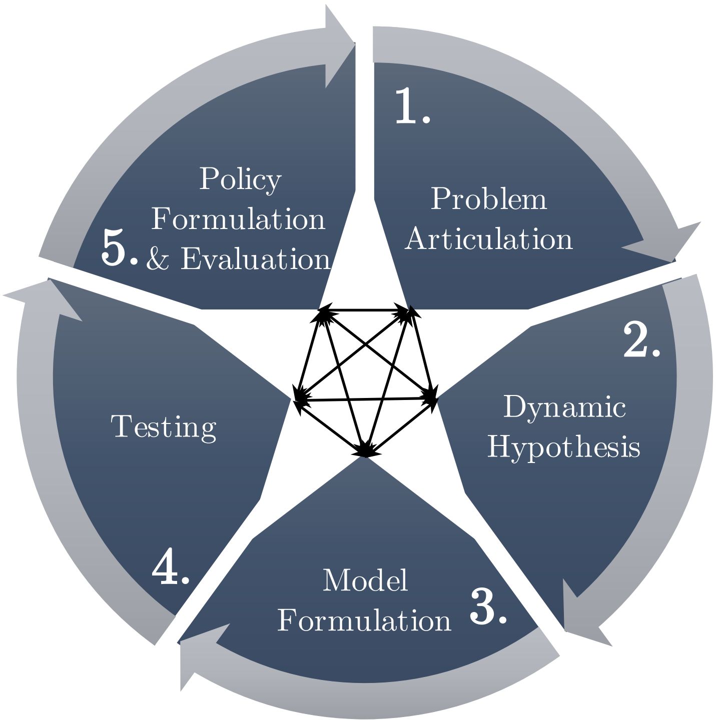


Figure 3.7. The System Dynamic Modelling Process (Adapted from Sterman, 2000, p.87).

3.3.1 Problem Articulation

Problem articulation is the most important step in modelling (Sterman, 2000). It aims to achieve full transparency throughout the organisation regarding how the model can be applied to solve the issue and the real problem, i.e. not just the symptom of difficulty. For a model to be useful it should address a specific problem and a limited set of issues rather than mirroring the entire system (ibid).

3.3.2 Dynamic Hypothesis

A dynamic hypothesis characterises the problem at hand in terms of feedback structure and stocks and flows throughout the system (Sterman, 2000). The dynamic hypothesis is constantly under revision, provisional or abandoned throughout the modelling process as new learnings are acquired throughout the process. During the dynamic hypothesis, conceptual models are created to express elements and factors that are included respectively excluded from the system (ibid).

When developing a dynamic hypothesis, a lot of data used is acquired from communication and interviews with people in the organisation (Sterman, 2000). This form has proven particularly effective when gathering modelling data. Data from interviews are, however, seldom adequate and must then be supplemented by other data sources, both quantitative and qualitative. It is important to gather data from all involved parties, at multiple levels, of the organisation as people tend to only have a partial understanding of the system (ibid).

Stock and Flow Diagrams
When sufficient interviews have been conducted, it is time to apply collected data into stock and flow diagrams (Sterman, 2000). In order to develop a good representation of the problem situation, it is recommended to supplement the data from interviews with other data sources, e.g. archival data and own expertise or experience (ibid).

Stocks are accumulations that generate information and characterise the state of the system which is used as a base for actions and decisions (Sterman, 2000). The balance of a stock depends on the ratio between in- and outflows. A thorough understanding of stocks and flows leads to a better estimation of time delays and long-term focus (ibid). The notation for stock and flow diagrams can be seen in Figure 3.8.

A stock and flow also consist of variables connected with casual links and link polarities to show influences and interrelations (Sterman, 2000). There are two link polarities; positive and negative. A positive link indicates that the variables move in the same direction, i.e. if one element increases (decreases) the other element will increase (decrease) as well. Negative links indicate that the variables move in opposite direction, i.e. if one element increases (decreases) the other element will decrease (increase). When deciding upon a link between two variables,

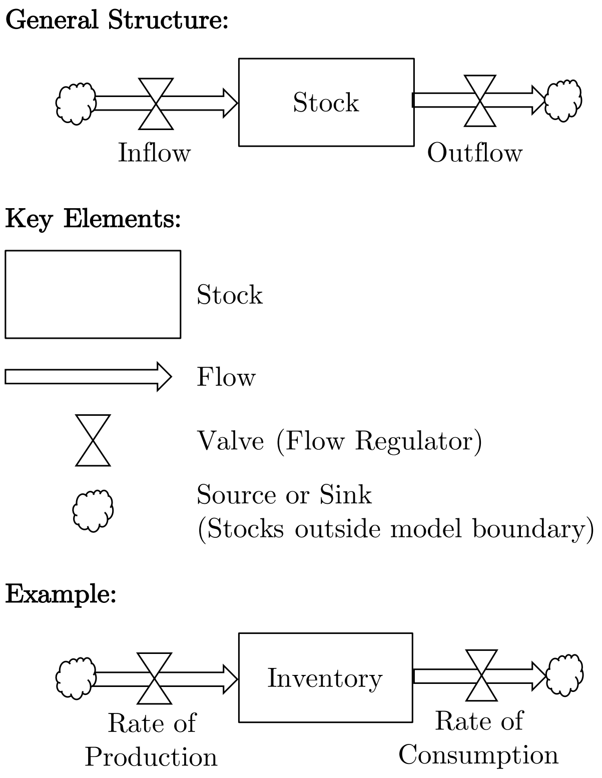


Figure 3.8. Notations of a stock and flow diagram (Adapted from Sterman, 2000, p.193).

it is vital to differentiate between causation and correlation. Including correlations between variables can lead to terrible misjudgements and policy errors as they reflect the past behaviour and not the structure of the system. If circumstances change, so can the correlation between variables. Causation, however, captures the relationship that will always occur even if circumstances were to change (ibid).

3.3.3 Model Formulation

Once the problem is articulated and all steps in the dynamic hypothesis are done, they need to be tested (Sterman, 2000). Sometimes it might be enough to test the system directly through data collection, however, if the conceptual model is deemed too complex, a simulation model needs to be formulated to clarify the dynamic implications. During this step, all equations, parameters and initial conditions required are identified and implemented in the model. Formalising a conceptual model will often further increase the general perception of the system and helps the modeller to find vague concepts (ibid).

3.3.4 Testing

In order to ensure credibility of the model, validation, verification and testing (VV&T) techniques can be applied throughout the whole modelling process (Balci, 1994). The model is validated once the model behaves with a satisfactory accuracy within its domain of applicability. Model verification is ensuring that the model is built right, i.e. that the model specification meets the problem formulation. Both verification and validation can be performed by model testing where inaccuracies and errors of the model are to be found and fixed. During the credibility assessment of a reasonably complex simulation study, subjectivity will always be apparent since the assessment is situation dependent and the modelling itself is an art. The key is to continue testing the model until all concerned parties achieve sufficient confidence, which is dictated by the study objective. (ibid).

Balci (2001) categorises VV&T techniques into four different assessment perspectives which can be seen in Figure 3.9. The complexity and mathematical formality differ from informal (to the left) to formal (to the right) (ibid).

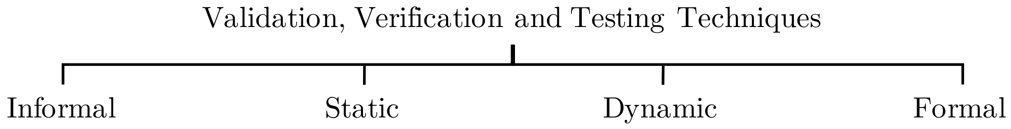


Figure 3.9. The four categories of VV&T techniques (Balci, 2001).

Informal VV&T Techniques

These are called informal as the VV&T techniques focus and rely heavily on human reasoning and less on mathematical formalism (Balci, 1994). The name informal does, however, not imply that the techniques lack structure or formal guidelines. VV&T techniques in this category are among the most common ones.

- **Desk Checking** – Particularly useful early on in the modelling phase and is the process of thoroughly examining the correctness, completeness, clarity and consistency. This process is preferably performed by another person as the modeller might be biased.
- **Face Validation** – Performed by the end users, project team members or entities familiar with the system under study. It is the process of comparing model behaviour to system behaviour, under identical input conditions, to judge the feasibility of the model's result.
- **Walkthrough** – The modeller prepares and distributes a documentation of logic used for the modelling process to entities not associated with the model itself. The modeller then gives a walkthrough in the form of a presentation of both the logic but also the made assumptions. It is important to avoid appraisal to the modeller during this process as it might disrupt discussions that could uncover faulty assumptions or logic (ibid).

Static VV&T Techniques

Static VV&T techniques focus on accuracy assessment on the source code of the model (Balci, 1994). The coding language of which the model is based on is itself a static VV&T tool which helps the coder to identify faulty code.

- **Consistency Checking** – Substantiate that; no contradiction occurs in the model representation, the cosmetic style of the code is used consistently, e.g. use of upper and lower case for variables, and data elements are manipulated consistently.
- **Syntax Analysis** – Assuring that the code is applied correctly. This is carried out by the coding language compiler (ibid).

Dynamic VV&T Techniques

These techniques require model execution and help to evaluate the model's behaviour during execution. Model instrumentation, i.e. additional codes inserted in the executable model that collects information about the behaviour, is key for VV&T techniques (Balci, 1994).

- **Debugging** – This is an iterative process with the purpose to find misconception or errors during the model execution. When an error is found, the cause is identified and changes required is put in place. Next step is to execute the model to see if the change causes another error. This process continues until no further errors are found.
- **Sensitivity Analysis** – Performed by systematically changing input values and parameters to see the model behaviour and uncover flaws in the programming. Furthermore, this VV&T technique can be used to find which scenarios or input parameters the model is sensitive to and then address that to end user to enhance model validity.
- **Symbolic Debugging** – Similar to debugging but instead the modeller set breakpoints in the model to allow for a step-by-step debugging to follow the model's outputs. When an error occurs, the modeller can use the debugger to find the cause (ibid).
- **Data Interface Testing** – Assessing the accuracy of input and output data after execution, substantiating that the model calculations are correct (Balci, 2001).

Formal VV&T techniques

Formal VV&T techniques are based on mathematical proofs. If mathematical proofs can be attained, formal VV&T techniques are the most effective way to assess a model (Balci, 2001). Proof of correctness is a formal VV&T technique where the model is presented in precise notations and then mathematically show that the executed model terminates with satisfying results based on the specification (ibid).

3.3.5 Policy Formulation and Evaluation

Once everyone involved is confident in the behaviour and structure of the model, it can be used to design and evaluate policies (Sterman, 2000). Policy design involves the creation of entirely new decision rules, structures and strategies. When testing various policies in the model, both the robustness of the model and the interference between policies can be clarified. Since real systems are nonlinear, the impact of all policies might not be the sum of their impacts alone because of balancing and reinforcements among the defined variables (ibid).

3.4 Simulation Tool for Climate Targets

In order to grasp the dynamic of the system and successfully modelling it, all of the theory presented in the frame of reference was combined and used as an input during all the steps of system dynamics modelling. The SBTi thoroughly explains the underlying problem and give a basis to how the GHG inventory of the Scope 3 emissions was calculated. The value chain emission section provides previous research's take on drivers and feasible mitigation efforts in the area studied. It will also allow for a gap-analysis by combining literature with the empirical data collected, thus minimising the risk of missing drivers and solutions. The system dynamics modelling process is used to comprehend and communicate the dynamics of the system as well as to formulate the simulation tool. A summary of the used components for each area addressed is presented in

Figure 3.10.

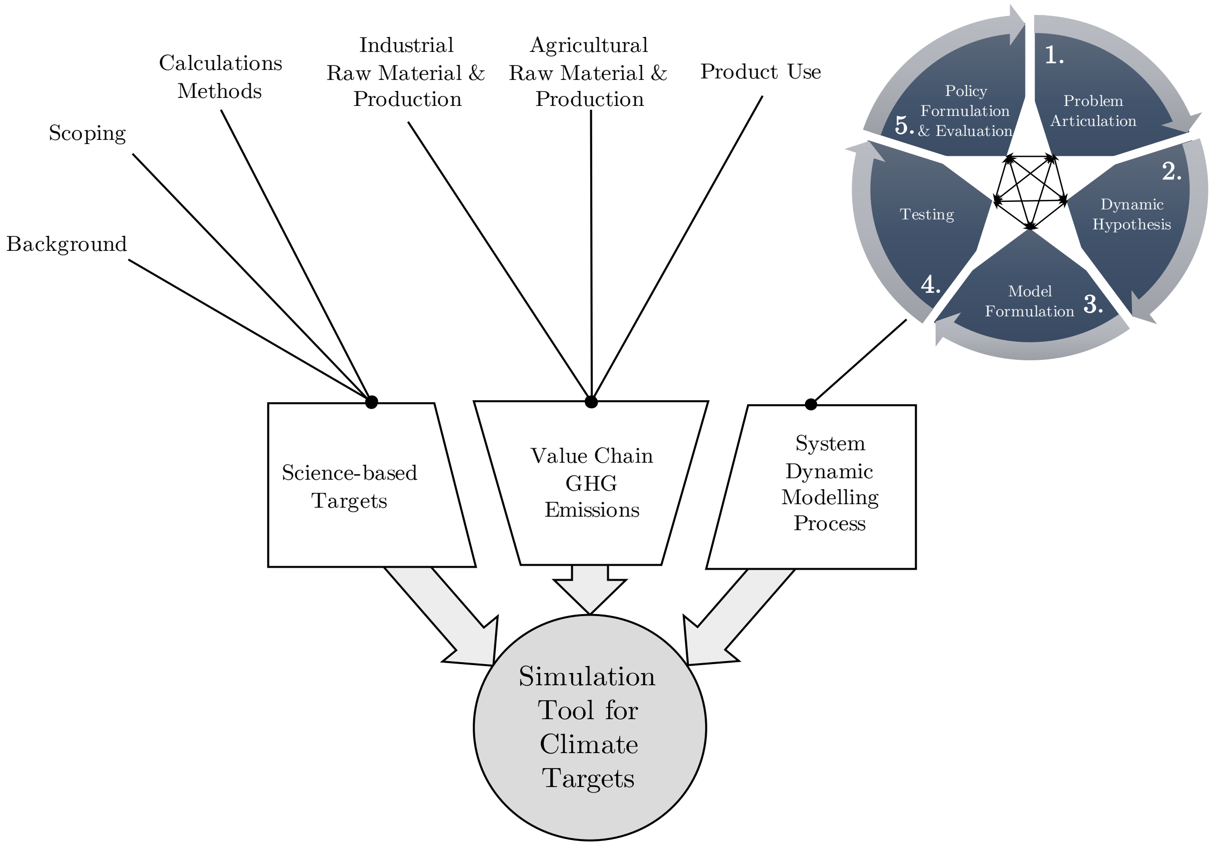


Figure 3.10. Summary of the components used for each area in the frame of reference.

4 Empirical Data

In this chapter, the empirical data that was collected during the case study is summarised. This data is later analysed together with the literature presented in Frame of Reference when answering the research questions.

The empricial data in this chapter is structured into three parts; Section 4.1 Scoping, Section 4.2 GHG Inventory and Section 4.3 Emission Drivers and Mitigation Options. The first section relates to the scoping in the project with especial focus on the areas covered in this research. It presents a more detailed description on the specific emission categories, together with sub-categories, that were encompassed in the simulation tool.

Derived from the scoping of the project and simulation tool, the GHG inventory is then further described in the following section. This section includes the methodology for quantifying the GHG inventory for the identified emission areas. In addition, it presents an explanation of how data quality was assessed as well as which data granularaity to strive for in the future.

Lastly, Section 4.3 Emission Drivers and Mitigation Options presents the empirical data that was collected relating emission drivers and steering parameters in the project. This data is primarily based on the five workshops held during the course of this research.

4.1 Scoping

Derived from the scoping already defined in the project, further assessment of the emission categories had to be carried out to define the final scope of the GHG inventory. The categories were assessed using the guidance supplied in GHG Protocol (2011) regarding criteria for including or excluding an emission category. Based on the assessment done by stakeholders in the project, the following emission categories were identified to be included in the simulation tool:

- Purchased Goods & Services
- Use of Sold Products

Applicability of the emission categories, with complementary sub-categories, for the different units included in the project was further assessed to avoid overlaps and double counting. A summary of the scoped emission categories to be addressed in the simulation tool is found in Table 4.1.

Table 4.1. The scoping of the emission categories that were included in the simulation tool.

Scope 3 Emission Category	**Sub-category**	**Applicable IKEA Units**	**More specific Sub-category**
1. Purchased Good and Services	Extraction, production and transportation of materials for purchased products	IKEA of Sweden	1. Raw material for purchased home furnishing products
			2. Raw material for purchased packaging material (not from IKEA Components)
		IKEA Components	1. Raw material for purchased components
			2. Raw material for purchased packaging material
		IKEA Food Services	1. Food ingredients for food products
			2. Packaging material for food products
	Production of purchased products	IKEA of Sweden	1. Production of home furnishing products
		IKEA Industry	1. Production of home furnishing products
		IKEA Components	1. Production of components
			2. Production of packaging material
			3. Packaging of purchased components
		IKEA Food Services	1. Production of food products
11. Use of sold products	Direct use-phase emissions	IKEA of Sweden	

4.2 GHG Inventory

As the scoping of the of emission categories determines the baseline for the simulation tool, the emissions for these categories had to be quantified in a GHG inventory. This was primarily done in the working units with additional support of a data analyst and the authors. The process of collecting data for the GHG inventory was an iterative activity, refinements and adjustments to the data were carried out throughout the whole modelling process.

The methodology for quantifying the GHG emissions related to the categories found in Table 4.1 was defined in the project using four emission areas:

- Raw Materials
- Food Ingredients
- Production
- Product Use

4.2.1 Raw Material Footprint

This footprint encompasses the sub-category "Extraction, production and transportation of materials for purchased products" in Table 4.1.

The raw material footprint is calculated using an emission factor (EF) covering all emission-related activities upstream in the supply chain of a material before it arrives at first tier supplier for further processing. The EF is composed of two parts, one relating the extraction of the material and one to address any material transformation that has occurred before the first tier supplier. The EF is based on the characteristics of a material, examples of materials and configurations are given in Table 4.2. In total was approximately 200 unique EFs used for the simulation tool.

Table 4.2. Examples of materials and configurations in the material GHG inventory.

Material	**Material Form**	**Recycled/ Virgin**	**Renewable/ Fossil Based**
Aluminium	Ingot	Virgin	Fossil Based
Aluminium	Ingot	Recycled	Fossil Based
Polypropylene (PP)	Granulate	Virgin	Renewable
Polypropylene (PP)	Granulate	Recycled	Fossil Based

By combining the purchased weight of a specific material configuration with its corresponding EF, the emissions relating the material was calculated, see Figure 4.1. The granularity of data was assessed including documentation of information source and potential error interval.

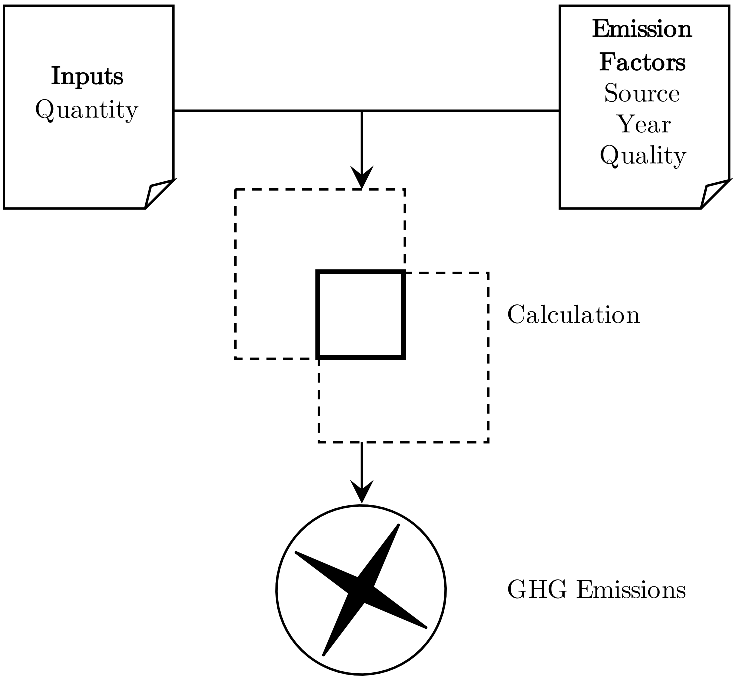


Figure 4.1. Calculation methodology for raw material GHG emissions.

4.2.2 Food Ingredient Footprint

This footprint is also included in the emission sub-category "Extraction, production and transportation of materials for purchased products" in Table 4.1. However, this footprint specifically refers to the ingredients in the food products.

Emissions relating food ingredients are calculated using the same principal presented in Figure 4.1. Ingredient data encompasses type, form, amount and sourcing country. Approximately 360 unique EFs were used for the simulation tool.

4.2.3 Production Footprint

The production footprint covers the emission sub-category "Production of purchased products" in Table 4.1.

The selection of calculation method for the production footprint was assessed using the Technical Guidance for Calculating Scope 3 Emissions (GHG Protocol, 2013, p.20-35). In order to address these, data needed to be collected using various tools. The full overview of the tools and calculation methods that were applied to quantify the GHG emissions for different units are found in Table 4.3.

Table 4.3. The calculations methods and tools for the different units.

Unit	Calculation Method	Tool
IKEA of Sweden	Supplier-specific method	Supplier Sustainability Index tool
IKEA Components	Supplier-specific method	Supplier Sustainability Index tool
IKEA Industry	Supplier-specific method	QlikView
IKEA Food Services	Average-data method	GHG Footprint Estimation Model for First Tier Food Suppliers

Further descriptions of the tools used to gather the data are given below.

Supplier Sustainability Index (SSI) tool

The SSI tool was used to gather the data for first tier home furnishing and component supplier (plastic and chemical raw material suppliers excluded). By having suppliers reporting their specific energy consumption of various energy sources, the GHG emissions connected to specific suppliers are calculated. The following operations are included in the scope of the reported data:

1. Energy consumption for production processes (e.g. electricity or fuels for process heat, e.g. steam)
2. Energy consumption for buildings (e.g. heating, lighting, etc., including offices and warehouses)

3. Energy consumption for internal transport (i.e. on-site forklifts and trucks, not outbound transports)
4. Refrigerants for cooling processes (e.g. production cooling, air conditioning, etc.)

To calculate the GHG emissions connected to these operations, the source of the conversion factors from different emission sources are presented in Table 4.4.

Table 4.4. The conversion factors' sources for the different emission sources.

Emission Source	Conversion Factor Source
Electricity	1. *Renewable energy*: IEA - World Energy Statistics 2016 (2014 data, section III, p.47-52)
	2. *CO_2 emission*: IEA - CO_2 Emission from Fuel Combustion 2016 (2014 data, section II, p.64-66)
Fuels for Combustion	1. GHG Protocol: Emission Factors from Cross-Sector Tools (April 2014)
	2. GHG Protocol: Global Warming Potential Values (using IPCC Fifth Assessment Report, 2014 (AR5))
Refrigerants	1. GHG Protocol: GHG emissions from refrigeration and air-conditioning (tool)

QlikView

The data collected via QlikView addresses the same operations and as the SSI tool, the same conversion factors was applied when calculating the GHG emissions.

GHG Footprint Estimation Model for First tier Food Suppliers

The GHG emissions relating the production of the first tier food suppliers are calculated using an estimation model. The estimation model uses two main types of data to define a processing profile for each product; food categories and storage, see Table 4.5.

Table 4.5. The estimation model for emissions relation first tier food suppliers.

Processing profile	**Frozen**	**Chilled**	**Ambient**
Product A			🟩
Product B	🟩	🟩	
Product C		🟩	

Based on the processing profiles of each product, an EF is defined and multiplied with the weight of that product (in kg) per year, similar to the raw material footprint depicted in

Figure 4.1. This enables IKEA to obtain a first estimation of the potential first tier supplier impact from food products.

4.2.4 Product Use Footprint

The product use footprint covers the emission sub-category "Direct use-phase emissions" in Table 4.1.

Products areas where the direct use-phase emissions were quantified are compiled in Table 4.6.

Table 4.6. Product areas with direct use-phase emissions.

Product Areas	Emission Source	Description
Lighting	Electricity	Energy consumption of LED bulbs and lamps
White Goods and Appliances	Electricity	Energy consumption of ovens and cookers, kitchen extractors, fridges and freezers, microwaves, dishwashers and laundry appliances
Candles	Combustion of Fuel	Combustion of candles

For the electricity-consuming products, the emission is quantified in in the following principle way:

$$\begin{aligned} GHG\ emission_{electricity} &= Total\ expected\ lifetime\ electricity\ consumption\ per\ product\ (kWh) \\ &* electricity\ EF\ (kg\ CO_2\ eq/kWh)\ * number\ of\ products\ sold\ in\ report\ year \end{aligned}$$

The expected lifetime electricity consumption is calculated depending on their product classification. The formulas for each classification are summarised in Table 4.7.

Table 4.7. Calculation methods for electricity-consuming products.

Product Classification	Lifetime Electricity Consumption
Lighting	Energy consumption (W) * expected life-length (h)
Appliances (always on): Fridges, freezers, etc.	Yearly energy consumption (kWh/year, energy class dependent) * expected life-length (years)
Appliances (use-dependent): Ovens, hobs, etc.	Energy consumption per use (kWh/use) * uses per year * expected life-length (years)

For the combustion of fuels, the emissions are quantified in the following way:

$$GHG\ emission_{Compustion\ of\ Fuel} = Sold\ quantity\ in\ report\ year * EF$$

where,

EF = the emission factor (kg CO_2 eq/kg) of the combustion fuel.

4.2.5 Assessing Data Quality

During data collection, the data quality was systematically assessed and documented based on granularity and potential assumptions.

For emission category 1, "Purchased Good and Services" in Table 4.1, it was concluded that the highest level of quality would be achieved if IKEA could track all GHG emissions for each product during its whole lifecycle. However, in many cases, full LCAs are not available. Therefore, a data management plan was developed to assure full transparency of the data quality as well as to be able to track progress over time.

A summary of plans and requirements for the data in the four emission areas is given below.

Raw Material

In order to assess the GHG emissions associated with raw materials as precise as possible, suppliers should report full information on where the raw materials have been sourced from. A high level of detail of the information for raw materials allows more accurate EFs to be applied. These cover the specific conditions regarding the pre-processing of a raw material, e.g. the specific electricity footprint of the transformation of aluminium scrap feedstock to ingot.

Food Ingredient

The same criteria are addressed for this emission category as for raw material. A higher level of detail for the information regarding sourcing will allow more accurate calculations for the food ingredient footprint.

Production

The preferred method when calculating the production footprint is concluded to be the supplier-specific method as it allows the highest level of detail regarding the production operations. The SSI tool facilitates this to great extent in the as-is situation and the same methodology should be applied to production areas not covered by the tool.

Product Use

The objective is to strive for as accurate product specifications as possible when calculating the GHG emissions. This includes the development of an accurate method to map the energy consumption per use for use-dependent products.

4.3 Emission Drivers and Mitigation Options

Drivers that project stakeholders requested to be implemented in the simulation tool was collected during workshops, most often attended by the whole project team. More formalised input of these drivers were then collected from stakeholders with specific knowledge of the different emission areas. These were collected using four input parameters:

- **Drivers** – the denotation to be used for the specific driver.
- **How** – descriptive text that explains the driver and how it affects GHG emissions.
- **Measurable** – some drivers may not always be quantifiable and/or measurable. To capture this aspect, it was requested to state if it was measurable or not.
- **Example(s)** – to avoid misinterpretations of the driver, it was requested to give examples to further illustrate the influence.

A summary of the collected drivers is found in Appendix A Emission Driver Input.

In order to avoid bias to respective emissions area, all members of the project team discussed each area to submit their thoughts and potential mitigation strategies. A total of five workshops were held. The following section presents the outcome of all workshops. A summary of dates and participants for each workshop has already been addressed in Table 2.4.

4.3.1 Workshop 1 – System Dynamics Introduction

The first workshop was held as an introduction to the system dynamics modelling process. Preparation material was sent out beforehand in order to prepare the project team for discussions of interest for the project. This workshop focused on the global drivers which would affect more than one emission area. The primary global drivers were identified to be growth and location based. Growth, in this context, was identified as business growth as well as Gross Domestic Product (GDP) growth for the various countries where some sort of value chain activity occurs. Due to the high complexity of quantifying the GDP growth, was business growth decided to be the only one included in the simulation tool. By the end of the workshop, it was decided that all team members were to use the parameters stated in the introduction and formulate specific drivers and mitigation options in their respective area and send it by email. These drivers were further assessed and discussed during workshops 2, 3, 4 and 5.

4.3.2 Workshop 2 – Production

The emission categories that were addressed during this workshop involved the production footprint, presented in Section 4.2.3 Production Footprint. During the workshop, all of the said emission categories were addressed to both identify drivers and mitigation options.

The use of fuels and electricity in production, heating and internal transport all contribute to GHG emissions. As the electricity grid differs depending on the location of the supplier or manufacturer, some suppliers can have a small share of renewable electricity. If, however, they were to improve their share, by e.g. buying or generate renewable electricity, emissions will decrease. The fuels used in production, heating and internal transport also contributes a lot. Therefore, by e.g. substituting fossil fuels to biofuels, emissions will decrease. All substitution would, however, require an investment which all suppliers might not be able to take. Some fuels could potentially be substituted to renewable energy instead, but this needed further assessment to be quantifiable. Energy efficiency, i.e. output per energy unit, is another driver which, if improved, would lead to a decrease in energy consumption and emissions.

Lightweight solutions were addressed as a potential mitigation option for production. It was, however, deemed hard to quantify the impact on production emission as the new construction could consume more energy. This would need to be further assessed and evaluated to be quantifiable.

Refrigerants used for production contribute to emissions both when consumed but also due to leaking. There is a widespread of the GWPs for refrigerants, thus a change towards refrigerants with lower GWPs would decrease emissions. It is, however, not possible to change between all refrigerants as they operate under different temperatures.

4.3.3 Workshop 3 – Food Ingredient

The emission categories that were addressed during this workshop encompassed the food ingredient footprint, presented in Section 4.2.2 Food Ingredient Footprint. During the workshop, all of the said emission categories were addressed to both identify drivers and mitigation options.

The emission related to food ingredient is dependent on quantity and an EF (which include both the extraction and transformation EF).

The EF of a food ingredient is, like raw material, highly dependent on the origin of sourcing and type of material. The drivers that contribute most to sourcing are; yield, deforestation and chemicals used at the farm level. Thus, by increasing the yield, avoiding deforestation and decreasing the chemicals used at the farm level, the total emissions would decrease as this sourcing option would lower the EF. It is also important to focus on ingredients with the highest EF and looking at alternative substitutions which result in a lower footprint. It is, however, important to substitute to an ingredient which the customer still would buy. IKEA can also promote more sustainable dishes in order to reduce GHG emissions. When assessing the food ingredient emission intensity, meat was especially addressed as a focus area.

The quantity of ingredients bought was discussed. By reducing pre-customer waste, the quantity of purchased ingredients could be decreased. The pre-customer waste is, however, currently under assessment and, thus, it is not possible to quantify the impact yet. Furthermore, the customer consumption was discussed, e.g. post-costumer waste coming from customers buying more than they eat. However, like pre-customer waste, this is also under assessment.

4.3.4 Workshop 4 – Raw Material

The emission categories that were addressed during this workshop covered the raw material footprint, presented in Section 4.2.1 Raw Material Footprint. The raw material footprint is dependent on quantity bought and EFs regarding the extraction as well as the transformation of the material. Therefore, all of these areas were addressed during the workshop.

A discussion of the main drivers of extraction EFs was held. It was concluded that main drivers are sourcing options, e.g. virgin, recyclable or origin, deforestation. Feasible strategies of mitigation are, therefore; switching to materials with more sustainable sourcing, avoiding deforestation areas and increasing yield. Thus, it is highly relevant to gather and assess full LCAs on as many materials as possible.

The transformation EFs were then discussed and it was concluded that the main drivers of this factor were fuels and electricity used during the transformation process. The transformation EF still exists when switching to alternative materials, e.g. recycled or renewable, therefore the impact of this change will not be as significant compared to the extraction EF. Origin, however, has a high impact on transformation EFs as the energy mix differs from country to country and even supplier to supplier. The availability of bio-based fuels was also an area that was considered during these discussions. A further decrease of transformation EF can be achieved by increasing the yield during the transformation phase.

The quantity of materials purchased has a substantial impact on the IKEA footprint. This could be decreased if IKEA can exchange materials in their products to materials with less weight while maintaining the same function. Furthermore, new constructions and designs were addressed as a potential driver for emission reductions. More-from-less designs would reduce the overall quantity of materials used in products.

Circular economy has a big potential to drive a reduction of emissions. It is, however, hard to quantify the impact as of now.

Furthermore, was offsetting discussed during the workshop but since it is not allowed to include in SBTs, no further assessment was made.

4.3.5 Workshop 5 – Product Use

The emission categories that were addressed during this workshop involved the product use footprint, presented in Section 4.2.4 Product Use Footprint. The product use workshop was held with support from a product development engineer and a sustainability leader, to ensure that no drivers were left out because of insufficient knowledge in the project team. The main drivers of product use emissions were identified to be the energy consumed by the product and emissions from combustions of fuels.

There is a wide variety of products in the IKEA range that consumes energy when used. The most critical ones are appliances, lamps and bulbs. The influence IKEA has on customer behaviour, such as awareness programs to turn off the light, was deemed hard to quantify. Thus, IKEA should focus on areas where they can have the highest influence. The energy efficiency the products in the range was identified as such an area and could be steered by either; increasing the energy efficiency, which would require a push for innovations and technology change, or phasing out low-efficiency products. Furthermore, the need for a higher share of renewable electricity throughout all energy grids was discussed. If 100 percent renewable electricity were to be achieved, the footprint of appliances and lighting would decrease to near zero.

The burning of candles in customer homes emits GHGs. By switching to renewable candles, i.e. from paraffin to stearin, said GHG emissions can be decreased to near zero.

In some markets IKEA sells photovoltaic panels which can, if used accordingly, generate renewable energy for appliances and lighting, thus reducing GHG emissions. It is, however, hard to quantify the impact on IKEA's footprint as the customer might use the photovoltaic panels for other purposes. Therefore, this is deemed as an offsetting method which cannot be accounted for when calculating the GHG inventory in SBT.

5 Analysis

In this chapter, the empirical data will be compared with the theory regarding the Value Chain GHG emissions to answer the first two research questions. Analysis of these will serve as indispensable support when later addressing the third research question and designing the simulation tool in the following chapter.

The analysis in this chapter is structured into three sections for each emission area. Each section fulfils a function when answering the first two research questions. The outcome of the analysis will then serve as one of the ingoing factors that are considered when addressing the third research question and developing the simulation tool. The structure of analysis for the two chapters is further depicted in Figure 5.1.

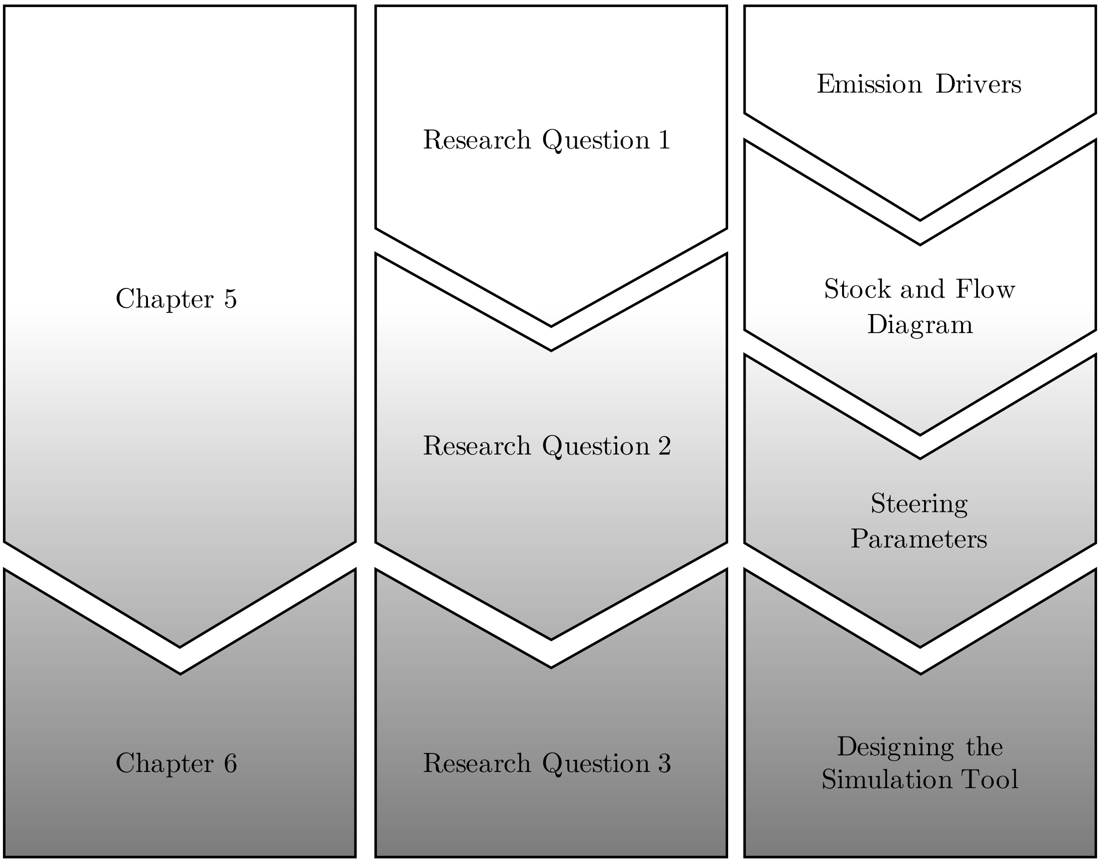


Figure 5.1. The structure of analysis when answering the three research questions.

In this chapter, a section regarding the emission drivers is first devoted to answer the first question, which the emission drivers of interest for the studied system are. All the drivers found during conducted workshops are connected to the literature presented in Section 3.2 Value Chain GHG Emissions. If any gap is found, i.e. literature states something that was not discussed during conducted workshops, the driver from the frame of reference will be assessed whether or not applicable for this project.

In the succeeding section, the methodology presented in Section 3.3.2 Dynamic Hypothesis is utilised to formulate stock and flow diagrams. These serve as the framework when explaining how the identified drivers are interrelated and influence each other, and thus giving a basis to begin answering the second research question. The drivers are categorised depending on their impact in the stock and flow diagrams to enhance the understanding and visualisation of events and influences occurring in the system.

Lastly, a third section summarises the identified emission drivers and answers the second research question. This section includes the analysis of the steering parameters that was deemed as feasible to include in the simulation tool. Note that this section only briefly presents the steering parameters by giving a short explanation to which driver it addresses. A more in-depth explanation of their corresponding functionalities will follow in Chapter 6 Designing the Simulation Tool.

5.1 Raw Material

This section covers the emission drivers, stock and flow diagram and steering parameters relating emission area raw material.

5.1.1 Emission Drivers

High and Low Impact Materials

This category focuses on the cradle-to-production related emissions of raw materials. There is a vast amount of drivers that contribute to a raw material's EF. By switching to more sustainable materials, emissions from raw materials can be decreased. The substitution can be between virgin to recycled material or even changing between two entirely different materials (Workshop 4, 2017). It might, however, not always be obvious which material that is the more sustainable option since the EF for materials are two-folded, i.e. one addresses the material extraction and the other any material transformation, e.g. pre-processing before first tier supplier gate (Workshop 4, 2017). As Napp et al. (2014) describe it, is it of high importance to have an LCA of each product when deciding upon potential substitutions. This is supported by Kuo et al. (2014) who stress the importance of delivering raw material footprint to the design departments to allow them to assess sustainable raw materials that can be used in the final product. Napp et al. (2014) also state that by switching to recycled and renewable plastics and metals energy saving can be achieved. Bio-plastic could potentially replace 90 percent of plastic and fibres used today. A factor to consider is, however, that the quality will decrease while the cost increases. Bergman et al. (2014) state that the forestry sector differs as the transformation EF of wood can be over 10 times as high as the raw material extraction EF (ibid). Thus, the potential of energy saving by using renewable or recyclable wood is not as high as for other materials. It is, however, as Bergman et al. (2014) state, important to note that wood, compared to many other materials, has a low EF (ibid). Thus, it is often a good material to address as a potential substitution alternative.

Lechtenböhmer et al. (2016) state that a high reduction of raw material transformation EF can be achieved by shifting to low-carbon energy sources. There are, however, a concern that low carbon energy sources might be limited in the future (Workshop 4, 2017; Lechtenböhmer et al., 2016). Furthermore, an assessment was made of future alternatives like applying electrolysis technique on iron ore and using electric furnaces to melt glass. Both these alternatives would decrease the EF of respective raw material but it is hard to quantify to what extent (ibid).

Resource Efficiency

When looking at resource efficiency, two different yields are important to consider. The downstream yield was discussed during Workshop 4 (2017), i.e. how well the ingoing resources are utilised. If the resource efficiency increases, the purchased quantity of both "High" and "Low" value material alternatives will decrease since less material is required to produce the same amount of products. The upstream yield, discussed during Workshop 4 (2017) and by Sathre and Gustavsson (2011), is the yield of raw material extraction. If the processes of raw material extraction are improved and less material goes to waste, the EF of said material would decrease.

Circular economy was also discussed as a mean of improving resource efficiency during the workshops. Lechtenböhmer et al. (2016), Napp et al. (2014) and Bergman et al. (2014) all discuss this matter as a form of resource sufficiency. Resource sufficiency is a central point of circular economy and involves prolonging product life and maintaining product design that allows for easier maintenance, repair and remanufacturing (ibid). Bergman et al. (2014) state that reusing wood, without recycling, the emissions are about one-fourth of when using virgin wood. IKEA is aware of the potential of circular economy and is in the process of implementing it in their operations. It is, however, for the time being, hard to quantify exactly how much material they can regain. Furthermore, the IKEA lightweight solutions were discussed as one of the major drivers for reducing raw material emissions (Workshop 4, 2017). Both Lechtenböhmer et al. (2016) and Napp et al. (2014) discuss lightweight solutions as a complimentary approach for sustainable production but refers to it as resource efficiency.

Offsetting

When assessing Scope 3 inventory, offsetting methods are not to be included (SBTi, 2015). The importance of offsetting was, however, discussed as it is still important to assess (Workshop 4, 2017). As Saud et al. (2015) state, wood products can act as carbon reservoirs which delay the emission of sequestered carbon back into the atmosphere. Lechtenböhmer et al. (2016) state that in order to achieve a decarbonisation of 70-90 percent for the industries of chemicals, cement, pulp and paper and steel CCS is the most viable solution.

5.1.2 Stock and Flow Diagram

For each of the following stock and flow diagrams in this chapter, the polarity of the links was given additional colour coding to enhance visual representation, blue refers to a positive connection and red represents a negative connection. Furthermore, since growth was identified as a global driver (Workshop 1, 2007) was it included as an emission driver for all following emission areas, including raw material.

The stock and flow diagram for raw material is presented in Figure 5.2. To capture the many configurations of a specific material; its material form, if it is recycled or virgin, if it is renewable or fossil based etc., they were represented in “High” and “Low”-value material alternatives as defined in Section 5.1.1 Emission Drivers. “High-Value Material Alternative” refers to a material configuration that has a higher GHG footprint intensity (higher EF) than other materials it is substituted for, denoted “Low-Value Material Alternative”. Substitution to these materials lowers the GHG footprint while consuming the same quantity of material. An example may be substitution from virgin to recycled aluminium or switching from fossil based to renewable plastics. Note that this is under the premise that the material substituted for having a lower EF.

Resource efficiency refers to all drivers that could not be quantified in terms of impact. This is due to the granularity of the data. However, an increase in resource efficiency would in most cases result in decreased amount of raw material purchased.

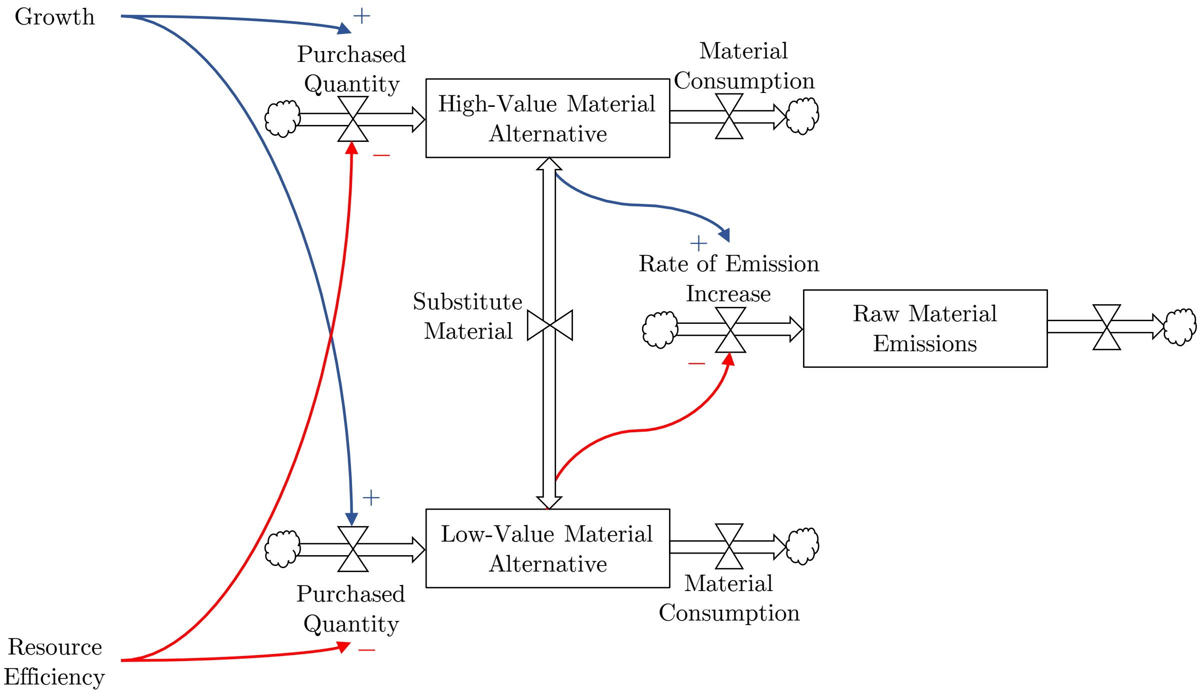


Figure 5.2. Stock and flow diagram for raw material.

5.1.3 Steering Parameters

As can be seen in Figure 5.2, are there two categories defined as high and low-value materials. Thus, a steering parameter allowing the user to substitute high impact materials towards low impact material supports the user for evaluating the impacts of potential emission reductions. A lightweight solution steering parameter is considered for the simulation tool to allow the user to reduce the quantity of a specified material. Lastly, altering CO_2 EFs was investigated to support steering directly on the specified materials EFs, both extraction EF and transformation EF. This was considered when addressing the resource efficiency which was deemed too complex to quantify. Therefore, the user is urged to make feasible assumptions when steering on resource efficiency. Said steering parameters and which emission driver they address can be seen in Table 5.1.

Table 5.1. List of steering parameters for raw material.

Steering Parameter Name	Address Emission Driver	Explanation
Substitute Material	High and Low-Value Materials	Allows the user to substitute materials.
Lightweight Solutions	Resource Efficiency	Allows the user to decrease the quantity of raw material used.
Altering CO_2 Emission Factor	Resource Efficiency	Allows the user to steer directly on the EFs of specified material.

5.2 Food Ingredient

This section covers the emission drivers, stock and flow diagram and steering parameters relating emission area food ingredient.

5.2.1 Emission Drivers

High and Low-Value Ingredient Alternative

As Garnett (2011) describes, food ingredients will emit GHGs throughout its whole lifecycle. This means that, after food is sold, IKEA still have to account for emissions from storing and preparation. Thus, ingredients that might have a low raw material EF might have a high storing EF from e.g. freezers or fridges. When assessing the EFs of food ingredients a common finding is that meat and dairy both has a high EF (Garnett, 2014). This can be seen in Figure 3.6 presented by IPCC (2014). This realisation was also identified at IKEA (Workshop 3, 2017).

Resource Efficiency

Garnett (2014) emphasise the need to improve the yield of food, both at farm and production level. This was also discussed during the workshops as a possible mitigation option

(Workshop 3, 2017). Another way to improve the resource efficiency is by decreasing the pre- and post-consumer waste. This topic was discussed by IKEA (Workshop 3, 2017) and by Garnett (2014). IKEA is currently assessing the pre-customer waste but at the moment there are insufficient data. Hence, pre-consumer waste is scoped out.

Food Consumption Behaviour

As previously mentioned, reducing post-consumer waste is a possible mitigation option described by Garnett (2014). IKEA, however, states that it is complex to estimate how much influence they really have within this area as of now. Hence, no waste is further assessed. IKEA can, however, promote food with low EFs in an attempt to influence customer consumption behaviour, thus decreasing their food emissions (Workshop 3, 2017). Range re-engineering is another option to change customer consumption behaviour. By e.g. reducing the amount of meat and dairies in the range and develop low impact alternatives, emission would decrease. However, a downside to this could be a negative response from customers resulting in a decrease of sales (Workshop 3, 2017). Garnett (2014) states that reduction of meat and dairy consumption is of high priority to reduce emissions related to food ingredients.

5.2.2 Stock and Flow Diagram

Figure 5.3 shows the stock and flow diagram for food ingredients. In parity with raw materials, "High" and "Low"-value alternatives are used to express different sourcing alternatives for food ingredients. "Low-Value Ingredient Alternative" in this context is interpreted as a lower EF substitute for a "High-Value Ingredient Alternative", e.g. palm oil with a low risk of deforestation as an alternative to palm oil from areas with large-scale conversion of tropical forest (and thereby a higher EF).

Resource efficiency represents the same principal as for raw material, fulfilling the same function with less resources. It also refers to pre-customer waste.

Food consumption behaviour represents either communicating to customers to change their consumption behaviour or change the product range, thus reducing "High-Value Ingredient Alternative" while increasing "Low-Value Ingredient Alternative".

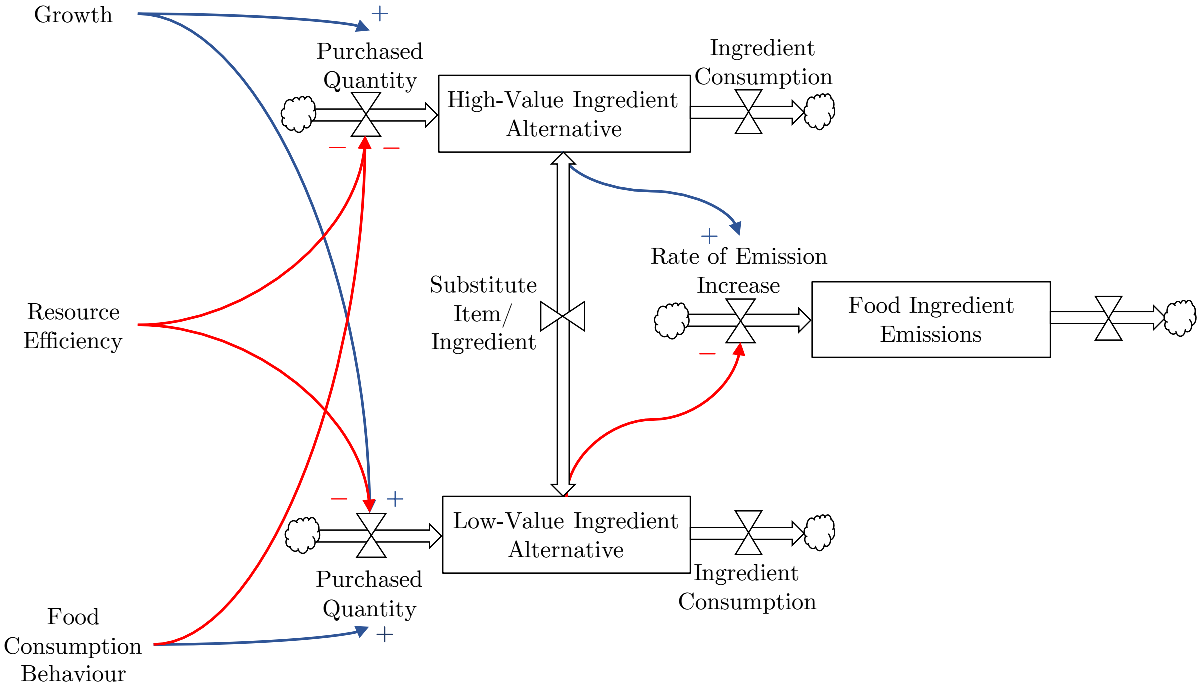


Figure 5.3. Stock and flow diagram for food ingredient.

5.2.3 Steering Parameters

As can be seen in Figure 5.3, is there an emission driver that encompasses categorisation into high and low impact ingredients. To address said categories, five steering parameters were identified. Relative share of item in product allows the user to decrease the quantity of a high-value item in a product while increasing the other, lower impact, item. Range re-engineering was considered to allow the user to create new products in the range. An item substitution parameter was considered to allow the user to change a specified (high impact) item in a dish to another (low impact) item. Targeted sales allow the user to increase and decrease sales of specified products, steering on high and low-value products. Lastly, altering CO_2 EFs was examined to allow the user to steer directly on the EF of specified ingredients. This is to support the user to steer on resource efficiency by quantifying e.g. the impact of increased yield at farm level for cocoa. Said steering parameters and which driver they address can be seen in Table 5.2.

Table 5.2. List of steering parameters for food ingredient.

Steering Parameter Name	Address Emission Driver	Explanation
Relative Share of Item in Product	Range Re-engineering	Decrease the quantity of specified item in product while increasing another.
Range Re-engineering	Range Re-engineering	Creating entirely new products to assess future emissions.

Steering Parameter Name	Address Emission Driver	Explanation
Substitute Item	Range Re-engineering	Can be used to change the item in a product or dish to another.
Substitute Ingredient Class	Range re-engineering	May be used to substitute ingredients.
Targeted Sales	Customer Behaviour	Increases/Decreases the sale of specified products.
Alter CO_2 Emission Factor	Resource Efficiency	Allows the user to alter the emission factor of specified ingredient e.g. letting the user quantify the impact of improved yield.

5.3 Production

This section covers the emission drivers, stock and flow diagram and steering parameters relating emission area production.

5.3.1 Emission Drivers

High and Low-Value Energy Sources

This category handles all energy sources, except electricity, used for production, heating and internal transport at the production site. The potential of reducing production emissions by switching from high to low-value energy sources, e.g. fossil fuels to bio-based fuels, is substantial (Lechtenböhmer et al., 2016). However, all IKEA suppliers might not be ready to take the required investment to make the change, or even have access to an infrastructure that supports such alternatives (Workshop 2, 2017). Also, might bio-based alternatives be of limited resources in the future (Lechtenböhmer et al., 2016). During the workshops, there was a discussion of changing some fuel sources to renewable electricity instead. This was, however, not considered for the simulation tool as an assessment is first required to evaluate for which areas this is feasible (Workshop 2, 2017). Lechtenböhmer et al. (2016) discuss the use of electric furnaces to melt glass instead of natural gas which could potentially reduce the IKEA production emissions. The conclusion was, however, also that further assessment is needed as it might not work on all qualities of glass (Lechtenböhmer et al., 2016).

Renewable Share of Electricity

By increasing the renewable share of electricity in production, all emissions related to electricity consumption will decrease (Workshop 2, 2017). Lechtenböhmer et al. (2016) state that renewable electricity is the energy source with least resource limits and negative impacts for the future. Great improvements in this area may, therefore, be explored.

Energy Efficiency

Energy efficiency is formulated as using less energy for producing the same amount of products (Workshop 2, 2017). This would require technological changes and a drive towards innovation (IPCC, 2014). Thus, it might be hard to evaluate when and how this can occur at a production site.

Leakage of Refrigerants

All refrigerant systems leak (Koronaki et al., 2012). Therefore, if the leakage of a system is mitigated, the IKEA emissions related to refrigerants will decrease (Workshop 2, 2017). Refrigerant leakage will also cause higher energy consumption in the production (Koronaki et al., 2012). Thus, the emissions related to energy consumption also decreases if leakage is counteracted. This matter was never discussed during the workshops. The impact was, however, deemed too hard to quantify.

High and Low-Value Refrigerant Alternative

The GWP values differ among refrigerants (Workshop 2, 2017; Koronaki et al., 2012). Thus, by switching to lower impact alternatives, a reduction of emissions can be achieved.

Lightweight Solutions

This was discussed during the workshop. However, it was deemed too complex to quantify in connection to the production emissions and, thus, excluded as a steering parameter (Workshop 2, 2017).

5.3.2 Stock and Flow Diagram

The production stock and flow diagram is presented in Figure 5.4. The sources of emissions within production is broken down to four sub-sources; internal transport, refrigerant, electricity, and fuel consumption for production and building. Energy efficiency relates to all four of these except for refrigerants. When increasing the efficiency, less energy is needed to produce the same number of products.

For the combustion of fuels for internal transports and production and building, the energy fuel sources have different EFs. “High-Value Energy Source Alternatives” include fossil-based fuels, e.g. oil and coal while “Low-Value Energy Source Alternatives” refer to biofuels with lower EFs. Substitution between energy sources is based on the same principal as for raw materials and food ingredients.

The primary reason for refrigerants to be an emission driver is from leakage of high GWP for many of the gases. Targeted reduction initiatives, see “Leakage Reduction” in Figure 5.4, can address these leakages and decrease the spillage which in return will decrease the filling rate. Substitution of refrigerants with high EFs toward low-value alternative is also captured in the stock and flow diagram using the same principal as for internal transport and production and building.

Emissions regarding electricity use are dependent on the energy mix suppliers’ source from and more specifically the renewable share in the mix. This is represented by a link that implies that when the renewable share of electricity increases, the rate of emission increase relating to electricity decreases.

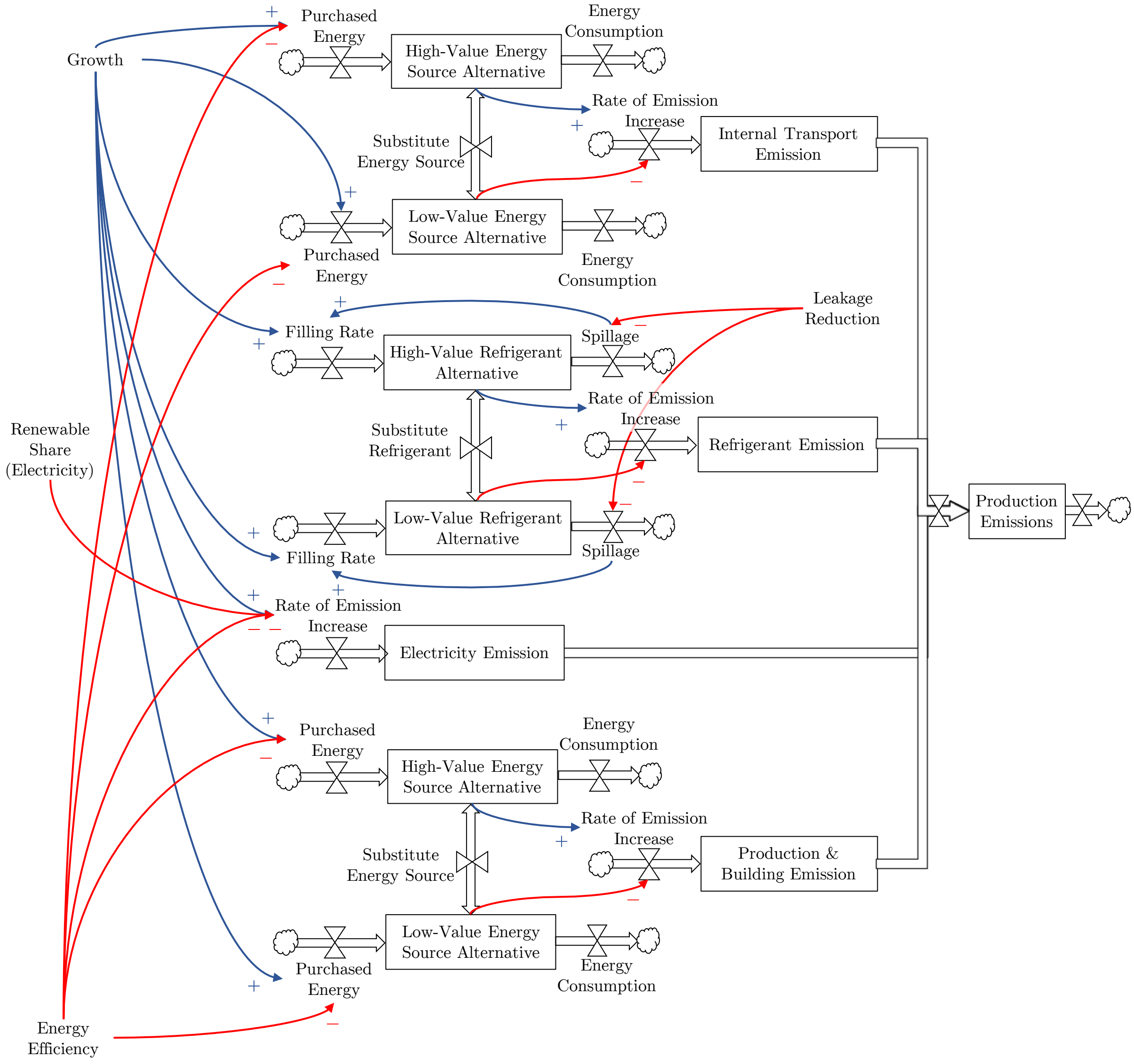


Figure 5.4. Stock and flow diagram for production.

5.3.3 Steering Parameters

To address the emission driver categories which can be seen in Figure 5.4, five steering parameters were formulated. Energy efficiency addresses energy efficiency and allows the user to decrease the energy consumption in all emission areas by specifying a percentage of decrease. Substitute energy source supports the user to change between high and low-value fuels. Alternating the renewable share of electricity allows the user to steer on the renewable share of electricity for specified suppliers which, if the new share is higher than previous, reduces emissions from electricity. Refrigerant spillage reduction addresses the leakage of refrigerants which reduces the quantity of refrigerants used in specified production. Lastly, substitute refrigerants were implemented to allow the user to change the refrigerants used in the production to refrigerants with lower (or higher) GWP. Said steering parameters and which driver they address can be seen in Table 5.3.

Table 5.3. List of steering parameters for production.

Steering Parameter Name	Address Emission Driver	Explanation
Energy Efficiency	Energy Efficiency	Decreases emissions by consuming less energy for the same amount of produced units.
Substitute Energy Source	High and Low-Value Fuel Source	Lower impact energy sources may be used to substitute high impact alternatives.
Renewable Share of Electricity	Renewable Share of Electricity	Lowering emissions through more sustainable electricity sourcing.
Refrigerant Spillage Reduction	Refrigerant and Leakage	Decreasing refrigerant consumption by leakage reductions.
Substitute Refrigerants	High and Low-Value Refrigerant Alternative	Substitution of high to low impact refrigerants.

5.4 Product Use

This section covers the emission drivers, stock and flow diagram and steering parameters relating emission area product use.

5.4.1 Emission Drivers

Energy Efficiency

During the workshops, energy efficiency and the need to push for innovations was widely discussed. IKEA recognises energy efficiency as the driver that would have both the highest influence and impact on customers' use of energy (Workshop 5, 2017). This can be done both by enhancing energy efficiency in the range but also by phasing out low energy efficient products (Workshop 5, 2017). In Table 3.2, Boone et al. (2012) highlight design for energy efficiency as the only mitigation option of customer use. Ardente and Mathieux (2014) also highlights this when stating that once the product has been put on the market, there is little to nothing a company can do to improve the products' sustainable characteristics.

Customer Behaviour

Jackson (2005) states that company awareness creation or information to customers is unlikely to make a significant impact on the customer use. IPCC (2014) states that the customer behaviour is hard to delineate as there is a wide variety of factors to consider. There is, however, potential that customers might go for energy efficient products if a company manage to provide proof to the customer that it is also the most cost-efficient alternative (ibid). Both these factors were taken into consideration. It was, however, concluded that even though IKEA might be able to influence the customer use, it is too complex to quantify (Workshop 5, 2017).

High and Low-Value Combustion Fuels

This category refers to all the emissions associated with the burning of combustion fuels, predominantly candles sold by IKEA. Within this area, increasing the share of stearin while decreasing the share of paraffin would lead to a reduction of emissions (Workshop 5, 2017).

Renewable Share of Electricity

IPCC (2014) mentions technology change and innovation as the key to reduce energy consumption. They do, however, highlight that the energy sector plays the key role in mitigation of customers' energy consumption as innovation and technology changes. By, for example, shifting to low impact energy fuels sources, there is potential to increase energy-efficiency without increasing the cost of electricity. As mentioned in Section Customer Behaviour, IKEA recognise their part in influencing customers but finds it hard to quantify. Hence, IKEA is dependent on innovations and technology change in the energy sector (Workshop 5, 2017).

5.4.2 Stock and Flow Diagram

The emission sources for product use were identified to be combustion of candles and other sold "fuels" as well as the electricity consumption relating the use of sold products, see Figure 5.5. For candles, "High-Value Fuel Alternative" relates to fossil-based paraffin wax while stearin, with a significantly lower EF, represents "Low-Value Fuel Alternative". Substitution from between these has the same influence as the previously presented relationships for high and low-value alternatives.

As for the electricity consumption of sold products, the emissions are dependent on the energy mix (and thereby the renewable share of electricity) of which the customers are using.

Energy efficiency for product use relate to how efficiently they fulfil their function, e.g. is the efficiency of a bulb expressed as the ratio between lumen (total quantity of visible light emitted by a source) and Watt (effect). The higher the efficiency, the less energy is required which reduces the emissions relating these products.

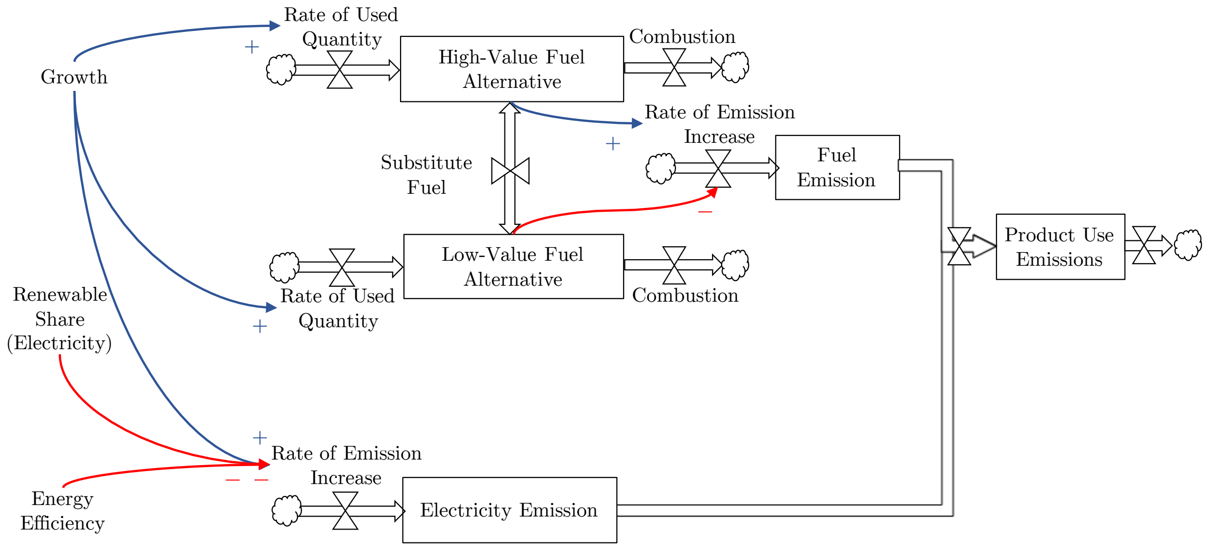


Figure 5.5. Stock and flow diagram for product use.

5.4.3 Steering Parameters

In order to address the categories presented in Figure 5.5, three steering parameters were identified to be implemented in the simulation tool. Energy efficiency allows the user to steer on the energy efficiency of specified products. Substitute product type support steering on phasing out specified products by exchanging them to other products. Lastly, renewable share of combustion of fuel was implemented to address high and low fuels. This steering parameter allows the user to change the share of candles to more (or less) renewable materials. Said steering parameters and which driver they address can be seen in Table 5.4.

Table 5.4. List of steering parameters for product use.

Steering Parameter Name	Address Emission Driver	Explanation
Energy Efficiency	Energy Efficiency	Steering on the energy efficiencies of the products in the range.
Substitute Product Type	Energy Efficiency	Allows steering on phasing out low energy efficient products
Renewable Share of Combustion of Fuel	High and Low-Value Fuels	Alters the renewable share of material in the product.

5.5 Summary of Emission Drivers and Steering Parameters

A summary of the identified emission drivers for each emission area is presented in Table 5.5 together with their corresponding steering parameters.

Table 5.5. Summary of emission drivers and steering parameters for each emission area.

Emission Area	Emission Drivers	Steering Parameters
Raw Material	• High and Low-Value Materials • Resource Efficiency	• Substitute Material • Lightweight Solutions • Altering CO_2 Emission Factors
Food Ingredients	• High and Low-Value Ingredient Alternative • Resource Efficiency • Food Consumption Behaviour	• Relative Share of Item in Product • Range Re-engineering • Substitute Item • Substitute Ingredient Class • Targeted Sales • Altering CO_2 Emission Factor
Production	• High and Low-Value Energy Sources • Renewable Share of Electricity • Energy Efficiency • Leakage of Refrigerants • High and Low-Value Refrigerant Alternative	• Energy Efficiency • Substitute Energy Source • Renewable Share of Electricity • Refrigerant Spillage Reduction • Substitute Refrigerant
Product Use	• Energy Efficiency • Renewable Share of Electricity • High and Low-Value Fuel Alternative	• Energy Efficiency • Substitute Product Type • Renewable Share of Combustion Fuel

6 Designing the Simulation Tool

This chapter presents the design of the simulation tool. The objective is to demonstrate its functionality with examples and application areas and, thereby, answer the third research question. In addition, the process for verification, validation and testing of the simulation tool is also presented to enhance transparency of its credibility.

In order to address the third research question, this chapter is dedicated to present the design and functionality of the simulation tool. The framework for doing so is presented in Figure 6.1 and presents the five ingoing factors that were considered when developing the tool.

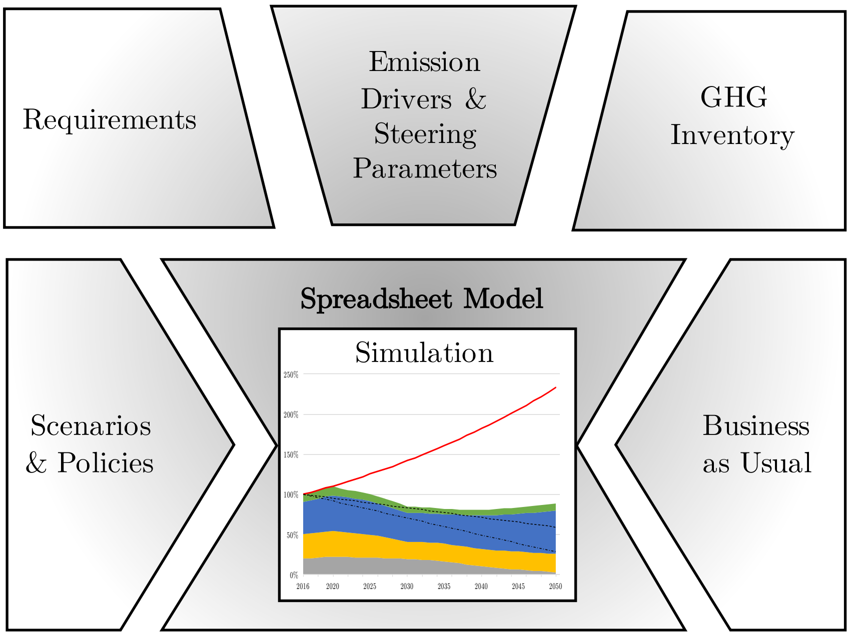


Figure 6.1. The ingoing factors considered when developing the simulation tool.

The requirements that determined the construction of the simulation tool was summarised before the start of the project and defined as:

1. Forecast the GHG footprint based on future growth and key parameters regarding materials, suppliers (production), and customer use of products.
2. Evaluation of policies that shows the impact of potential improvements to reduce the GHG emissions.
3. Supports development of climate targets by providing critical facts and insights from the analysis of the different data sets and the simulation model.
4. Supports policy evaluation on aggregated as well as on individual IKEA unit level and further sub-levels.

5. Supports evaluation of policies on three different time horizons; short-term (3-5 years), mid-term (by 2030) and long-term (by 2050).

As been discussed previously, a hybrid simulation approach was applied in this research. System investigation and mapping was done using the qualitative benefits of the system dynamics methodology for developing a dynamics hypothesis. The outcome of this process has been described and analysed in the two previous chapters. The ingoing emission drivers and steering parameters that were considered for the simulation tool is presented in summarised in Section 5.5 Summary of Emission Drivers and Steering Parameters. The simulation tool was implemented with the steering parameters, complete with equations and initial conditions, into a spreadsheet model.

The ingoing GHG inventory, presented in Section 4.2 GHG Inventory, served as the baseline for the simulation tool. The GHG inventory is crucial for the simulation tool as absolute climate targets must be formulated relative to the baseline inventory. Furthermore, the calculation methodology used for the GHG inventory was important to consider when implementing the simulation logic. If a different methodology is applied to calculate future scenarios and projections, there is a high risk of misrepresentative simulation results which may lead to ambiguous policy evaluations.

As an extension of the requirement to evaluate scenarios and policies, specific areas of interest among project stakeholders was also considered when developing the simulation tool. These were primarily identified during the workshops in combination with discussions of the emission drivers and steering parameters for the various emission areas.

A central component of the simulation tool was modelling of the business as usual (BAU) scenario. The BAU scenario is crucial for policy evaluation as it puts the impact of policies in relation to the normal course of the unaltered state of the Scope 3 emission system. This scenario is modelled using the baseline GHG inventory and projected future growth.

Verification, validation and testing of the simulation tool are, as previously noted, essential when evaluating the credibility of the model. Therefore, the process of doing so is presented in the last section of this chapter.

6.1 Steering Parameters

This section presents the steering parameters that was implemented in the simulation tool. The four emission areas are handled separately, followed by a section where a combination of scenarios and steering parameters is presented to highlight the aggregated and holistic functionality of the tool.

For each steering parameter, all input parameters required for the simulation are stated together with an explanation of their function. A more extensive description of the implemented calculations for the steering parameters is presented in Appendix B Simulation Tool Calculations. Furthermore, examples are presented for each steering parameter to demonstrate the application area for the specified parameter. The examples should be considered for reference only. The input parameters for all examples are summarised in Appendix C Input Examples.

The baseline year is set to 2016 for all examples. The simulations are based on an arbitrary growth factor set to an annual rate of 2,6 percent to reflect the average global economic growth up to 2050 (PwC, 2017). For each example, the variable dependent axis is expressed as an index in relation to the baseline (for example is the change of emissions up to 2050 relative the GHG inventory at the baseline year).

6.1.1 Raw Material

This section describes how the steering parameters related to emission area raw material, presented in Section 5.1.3 Steering Parameters, are implemented in the simulation tool. They are based on the GHG inventory and calculation methodology presented in Section 4.2.1 Raw Material Footprint.

For these steering parameters, the same material (Metal A) will be used in all examples. The implications of the various policies in the examples will first be presented in their corresponding sections. However, to fully capture the dynamics and overlap of different policies in combination, the result of all examples in one simulation is finally presented in Section 6.1.5 Combination of Scenarios and Steering Parameters.

6.1.1.1 Substitute Material

The steering parameter allows the user to substitute the quantity of a material for another and thereby evaluate the implications of different sourcing options. The input parameters for the steering parameter are summarised in Table 6.1.

Table 6.1. Input for steering parameter: Substitute Material.

Parameter		Explanation
Material	**From**	The material that will be substituted from.
	To	The material that will be substituted to. (This parameter could be set to the same as "Material (From)").
Material Form	**From**	The material form the material will be substituted from.
	To	The material form the material will be substituted to. (This parameter could be set to the same as the "Material Form (From)").
Recycled/Virgin*	**From**	Defines if the material that will be substituted from is recycled or virgin.
	To	Defines if the material that will be substituted to is recycled or virgin.
Renewable/Fossil Based*	**From**	Defines if the material that will be substituted from is renewable or fossil based.
	To	Defines if the material that will be substituted to is renewable or fossil based.
Weight Ratio		The weight ratio between the affected materials.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
New Share (%)	**From**	The remaining share (in relation to BAU) of the material that will be substituted. 0 percent implies that all the quantity will be substituted by the end of the policy.
	To	The share of the substituted material that will be allocated to the new material. If all quantity from the substituted material is allocated exclusively to this material, this parameter should be set to 100 percent.

**If this does not apply to the selected material, it may be left blank.*

Example

The following example evaluates the policy of gradually substituting virgin to recycled of a metal, denoted Metal A, between 2020 and 2030. By 2030, only 20 percent (in comparison to BAU) of virgin Metal A will remain, the rest has been substituted to a recyclable configuration. The result of the simulation is presented in Figure 6.2.

Note that the overall quantity (left graph) is the same as BAU since the weight ratio is set as 1:1. The quantity has only been redistributed from virgin into the recycled material alternative. The emissions, however, has decreased (in relation to BAU) due to the lower emission factor of the recycled alternative.

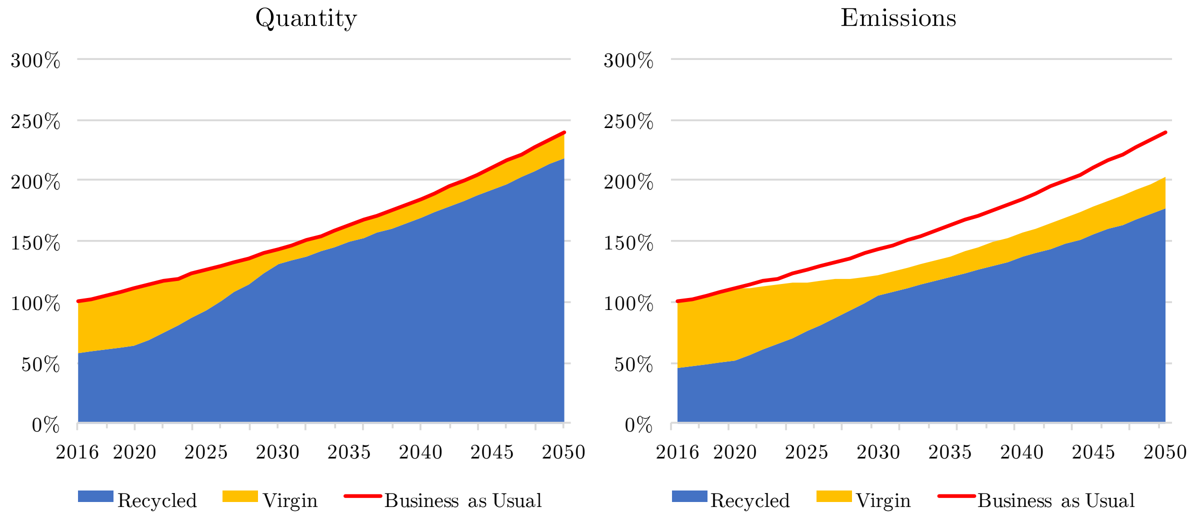


Figure 6.2. Simulation example for steering parameter: Substitute Material.

6.1.1.2 Lightweight Solution

This steering parameter allows the user to examine scenarios where new construction techniques enable a product to maintain the same functionality while using less material. The user can quantify a reduction percentage of the total quantity needed for specific materials. The input parameters for the steering parameter are summarised in Table 6.2.

Table 6.2. Input for steering parameter: Lightweight Solution.

Parameter	**Explanation**
Material	The material that will be affected by the lightweight solution.
Material Form	The material form of the affected material.
Recycled/Virgin*	Defines if the affected material is recycled or virgin.
Renewable/Fossil Based*	Defines if the affected material is renewable or fossil based.
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
Percentage of Change (%)	The final percentage of decrease for the specified material at the end of the policy (in relation to BAU).

**If this does not apply to the selected material, it may be left blank.*

Example

A new construction method, implemented in the product range gradually between 2020 and 2030, can reduce the material usage of Metal A (virgin and recycled) by 20 percent. Since the policy is targeted at two material configurations, two inputs must be filled in. The simulation result is presented in Figure 6.3.

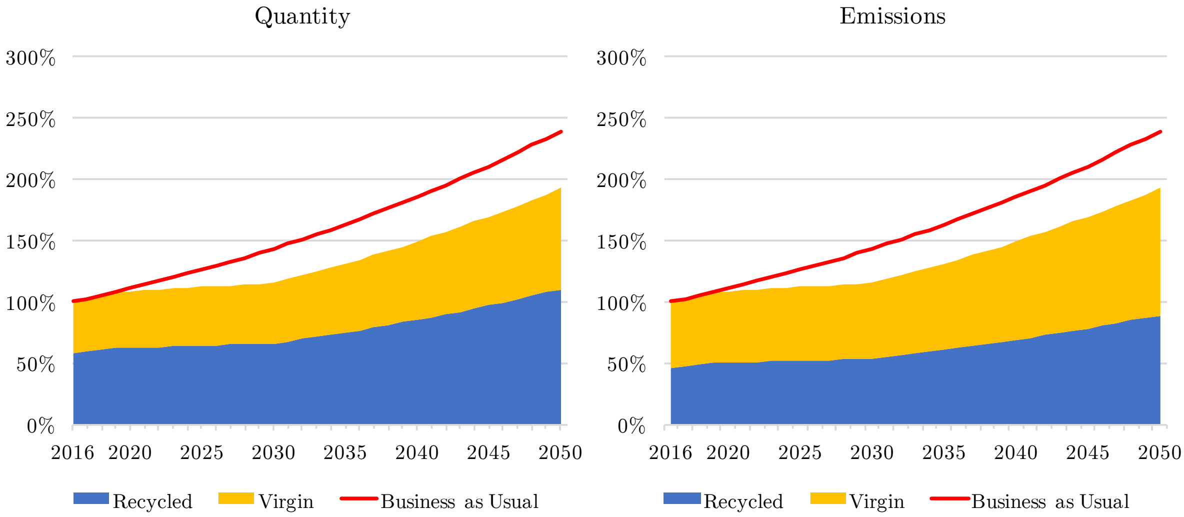


Figure 6.3. Simulation example for steering parameter: Lightweight Solution.

Note that in this policy, there is a perfect positive correlation between the reduction of emissions and the quantity (same percentage reduction can be seen in both graphs in Figure 6.3). It is therefore different from the steering parameter presented in Section 6.1.1.1 Substitute Material, where the total quantity remains the same level as BAU.

6.1.1.3 Altering CO_2 Emission Factor

The user is allowed to decrease/increase the emission factor of a chosen material, e.g. when setting a scenario to explore the implications of switching to a more sustainable pre-processing of a raw material. The material transformation share of the emission factor could then be targeted in this setting. The input parameters for the steering parameter are summarised in Table 6.3.

Table 6.3. Input for steering parameter: Altering CO_2 Emission Factor (Raw Material).

Parameter	Explanation
Material	The material which emission factor will be affected by the policy.
Material Form	The material form of the affected material.
Recycled/Virgin*	Defines if the affected material is recycled or virgin.
Renewable/Fossil Based*	Defines if the affected material is renewable or fossil based.

Parameter	Explanation
Emission Factor Type	Defines if the emission factor that is altered refers to the material extraction, the material transformation or both the material extraction and the material transformation.
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
Percentage of Change (%)	The percentage of decrease/increase for the affected emission factor at the end of the policy (in relation to the value at "Start Year").

**If this does not apply to the selected material, it may be left blank.*

Example

This example decreases the material transformation share of the emission factor for machined parts of Metal A (virgin and recycled) by 25 percent between 2020 to 2035. The result of the simulation is presented in Figure 6.4.

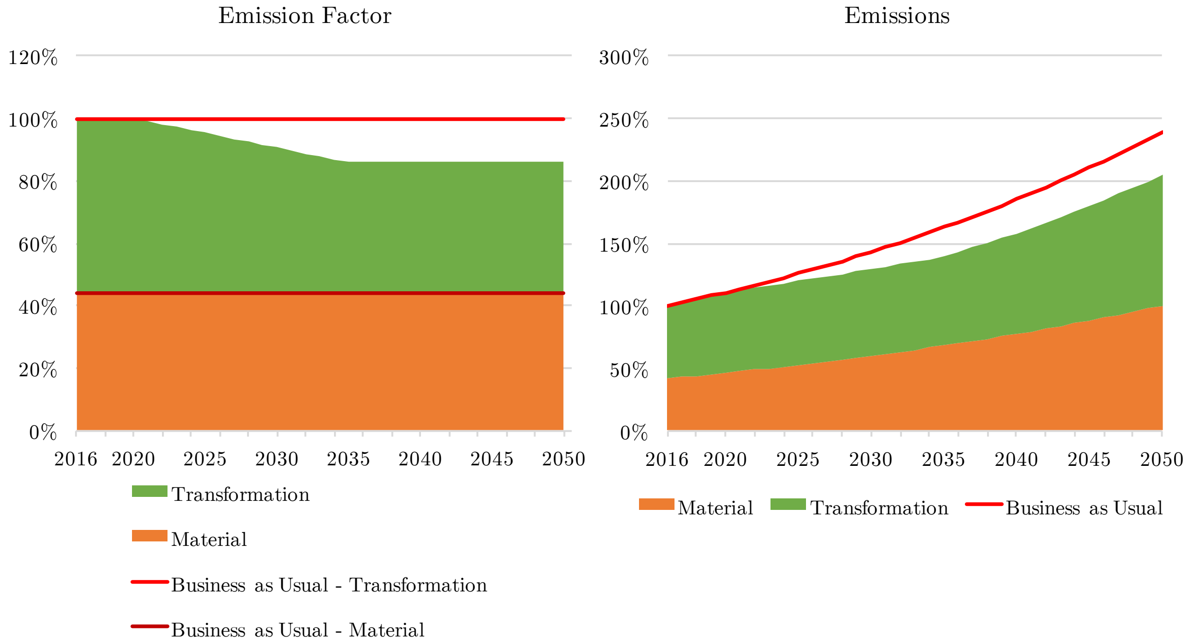


Figure 6.4. Simulation example for steering parameter: Altering CO_2 Emission Factor (Raw Material).

Note that the data presented in Figure 6.4 shows the aggregated values for both configurations of Metal A (both virgin and recycled). The material share of the emission factor is unaffected by the policy and remains at the BAU level throughout the simulation, see the left graph. However, the reduction of the material transformation share of the emission factor entails a reduction of the emissions (in relation to BAU). The quantity is unaffected by this policy.

6.1.2 Food Ingredient

This section describes how the steering parameters relating emission area food ingredient, presented in Section 5.2.3 Steering Parameters, are implemented in the simulation tool. They are based on the GHG inventory and calculation methodology presented in Section 4.2.2 Food Ingredient Footprint.

6.1.2.1 Relative Share of Item in a Product

The steering parameter allows the user to change the relative share of mass of an item within a product. The mass difference that is extracted and added between the items is distributed according to the relative share of mass of the ingredients that make up the item.

To further illustrate the concept, the relative shares (RS) of mass between items and ingredients are presented in Figure 6.5. The RS for an item of a product is presented above its label. The same principal is applied to express the RS for an ingredient of an item.

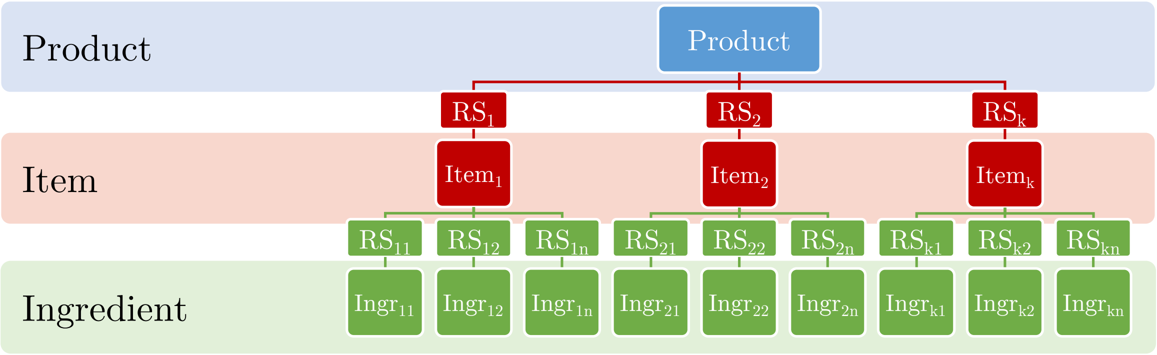


Figure 6.5. The concept for relative shares (RS) between items and ingredients.

The input parameters for the steering parameter are summarised in Table 6.4.

Table 6.4. Input for steering parameter: Relative Share of Item in a Product.

Parameter		**Explanation**
Product		The product in which the relative share of an Item is to be changed.
Item	**From**	The item that the relative share is to be altered.
	To	The item to which the mass is to be redistributed to.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as “Start Year” which would imply that the policy is completely implemented the same year as it is started.)
New Relative Share of Item (%)		The new relative share of mass of “Item (From)” in relation to “Product”.

Example

To further illustrate the concept of RSs, a product is exemplified in Figure 6.6 below.

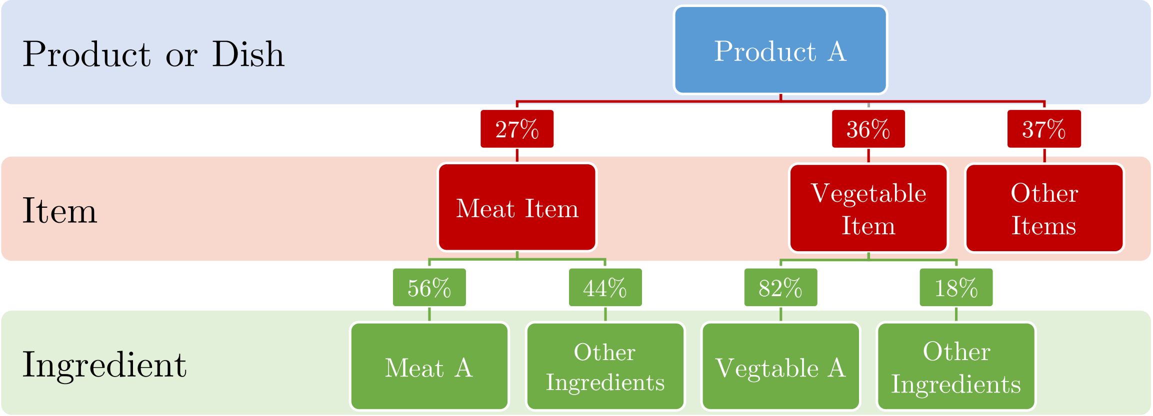


Figure 6.6. Example for steering parameter: Relative Share of Item in a Product.

"Meat Item" make up 27 percent of the total mass of the product ("Product A"). The same logic is applied for the RS of mass for an ingredient of an item, e.g. "Meat A" (Ingredient) make up 56 percent of the total mass of "Meat Item". In the policy, that is planned to be completely implemented 2020, the RS of "Meat Item" is set to 10 percent and the mass is redistributed to "Vegetable Item". The simulation result of the policy is presented in Figure 6.7 below.

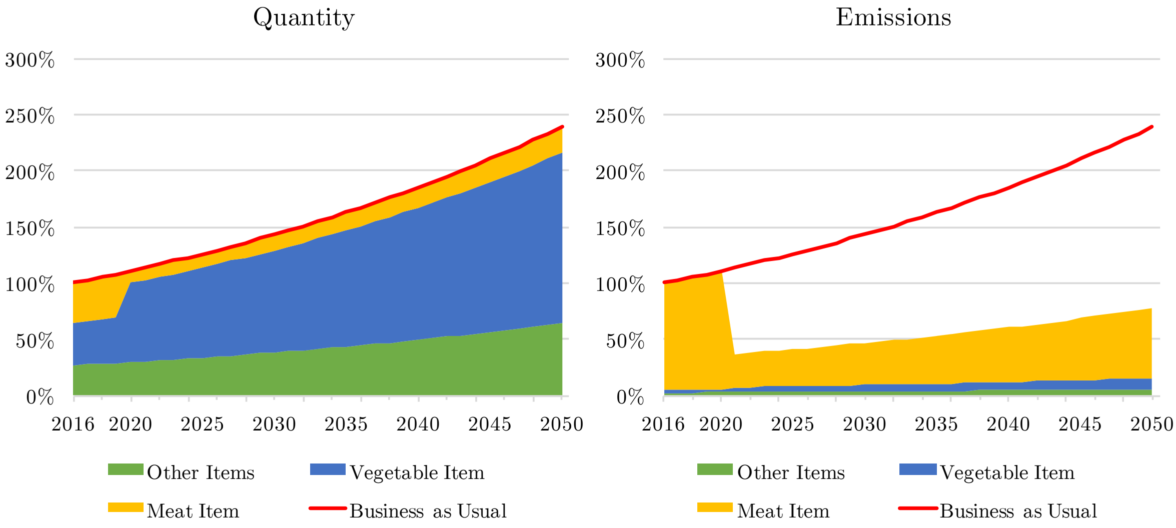


Figure 6.7. Simulation example for steering parameter: Relative Share of Item in a Product.

In similarity to the steering parameter presented in Section 6.1.1.1 Substitute Material, the overall quantity is unaffected by the policy, see left graph in Figure 6.7. The emissions, seen in the right graph, are, however, lower than the BAU scenario. This is due to the overall emission factors for the ingredients in "Vegetable Item" being significantly lower than the corresponding ones in "Meat Item".

6.1.2.2 Range Re-engineering

This steering parameter is used to create new products that currently does not exist in the product range. The user is allowed to add up to ten new products, with the constraint of maximum ten items in a product and 20 ingredients in an item. The input parameters for the steering parameter are summarised in Table 6.5.

The products are then integrated into the data set, initially with all quantities set to zero. Other settings may then be used to alternate the quantities in scenarios and policies.

Table 6.5. Input for steering parameter: Range Re-engineering.

Parameter		Explanation
Product Name		User denotation of the created product.
Item	1 - 10	Refers to an item that should be included in the new product.

Example

A new product “Vegetable Hot Dog” is created using two existing items; “Vegetable Sausage” and “Hot Dog Roll”. The new product created contains all ingredients included in the two existing items.

6.1.2.3 Substitute Item

This steering parameter is used to substitute an item in a product for another item. Using the same principal as the steering parameter presented in Section 6.1.2.1 Relative Share of Item in a Product, the mass difference that is extracted and added between the items is distributed according to the RS of mass of the ingredients that make up the item. The concept is presented in Figure 6.8, where an item or ingredient could be substituted between Product A and B (e.g. Item$_{A1}$ is substituted for Item$_{B1}$).

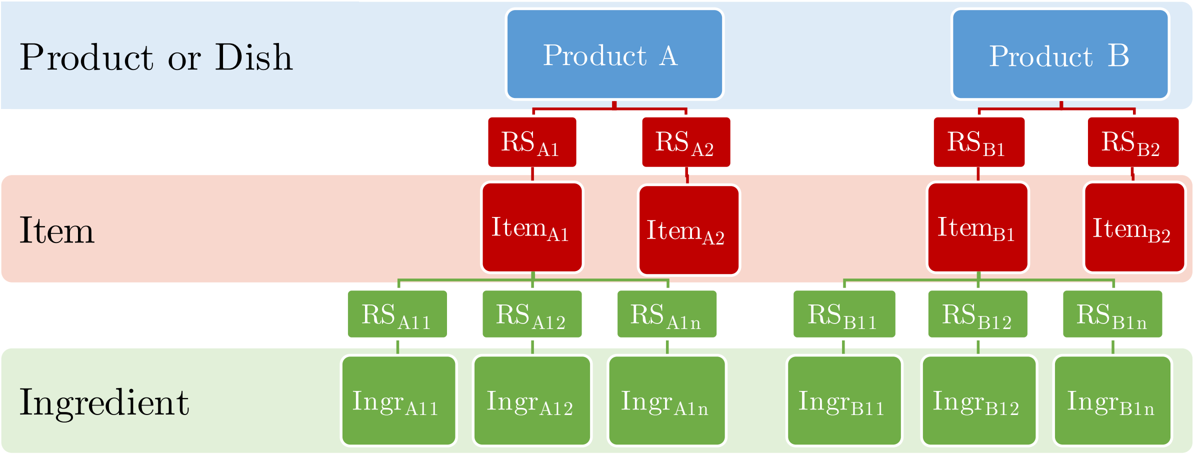


Figure 6.8. The concept of substitution of items between products.

This steering parameter could be used in combination with the one presented in Section 6.1.2.2 Range Re-engineering to simulate the scenario where a new product substitutes an existing. All items within the product must then be substituted for a corresponding one in the new product (e.g. Item_{A1} for Item_{B1}, Item_{A2} for Item_{B2}, Item_{An} for Item_{Bn}). The input parameters for the steering parameter are summarised in Table 6.6.

Table 6.6. Input for steering parameter: Substitute Item.

Parameter		**Explanation**
Product	**From**	The product in which the item is going to be substituted from.
	To	The product in which the item is going to be substituted to.
Item	**From**	The item from which the mass is going to be extracted from.
	To	The item from which the mass is going to be extracted to.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
New Share (%)		The percentage of change of mass from "From Item" to "To Item" at the end of the policy.

Example

This example substitutes the items in a "Hot Dog" product to the "Vegetable Hot Dog" created in the example presented in Section 6.1.2.2 Range Re-engineering between 2020 and 2035. Since it consists of two items, two inputs must be filled in. The simulation results of the example are presented in Figure 6.9. At the end of the policy, the new items make up 20 percent of the mass that they have been substituted from (compared to BAU).

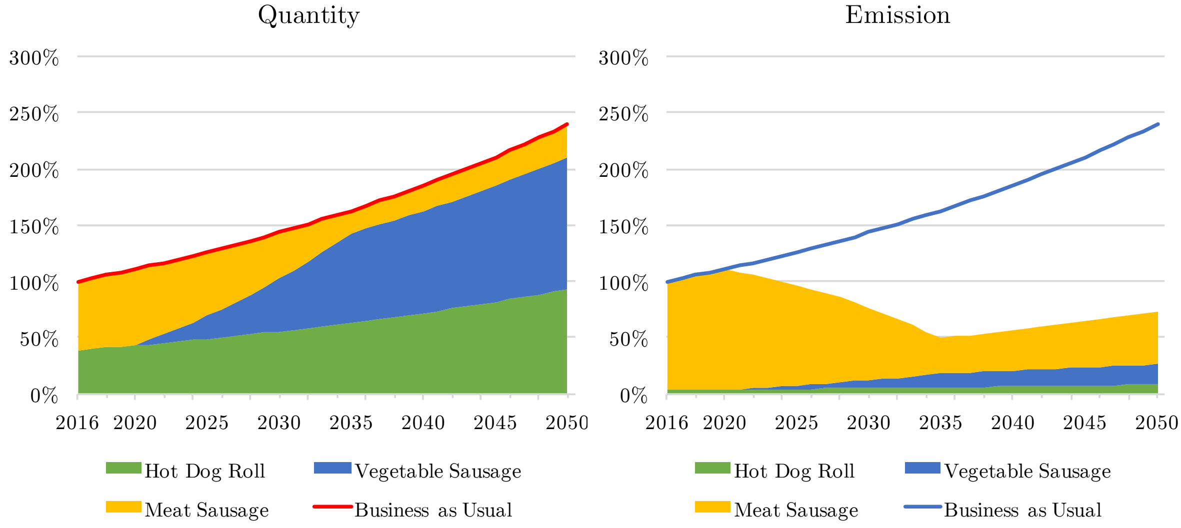


Figure 6.9. Simulation example for steering parameter: Substitute Item.

Rather than showing the two different products that have been substituted, Figure 6.9 presents the three items that make up said products. Since "Hot Dog Roll" is part of both products and just redistributed between them, the total quantity and emissions are unaffected (in relation to BAU) for this item throughout the policy. The overall emissions have decreased due to that the accumulated emissions from the ingredients in “Vegetable Sausage” are lower than the ones in the regular “Meat Sausage”.

6.1.2.4 Substitute Ingredient Class

This steering parameter is similar to the one presented in Section 6.1.2.3 Substitute Item. It is, however, aimed to be used at a higher aggregation level. Rather than substitution between specific items in products, the ingredients in a certain class are distributed according to the RS of mass of the ingredients in another ingredient class. The concept is presented in Figure 6.10, e.g. all ingredients in Ingredient Class A may be substituted for the ingredients in Ingredient Class B.

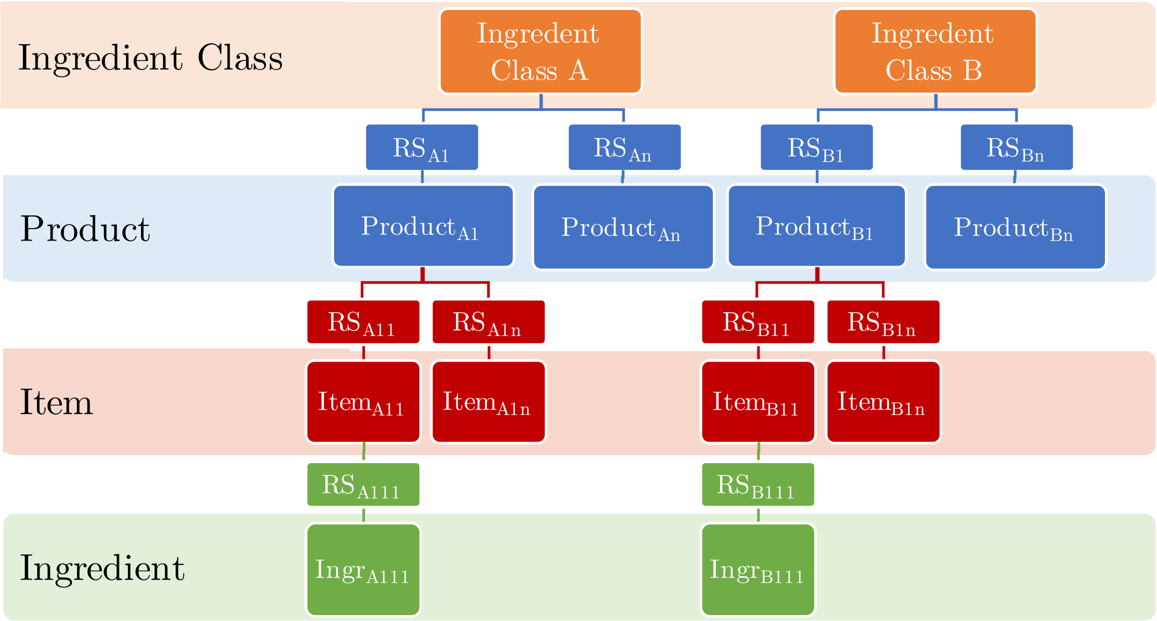


Figure 6.10. The concept of substitution between ingredient classes.

The input parameters for the steering parameter are summarised in Table 6.7.

Table 6.7. Input for steering parameter: Substitute Ingredient Class.

Parameter		**Explanation**
Ingredient Class	**From**	The ingredient class that the ingredients are going to be substituted from.
	To	The ingredient class that the ingredients are going to be substituted to.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as “Start Year” which would imply that the policy is completely implemented the same year as it is started.)

Parameter	Explanation
New Share (%)	The percentage of change of mass from “From Ingredient Class” to “To Ingredient Class” at the end of the policy.

Example

This example substitutes the ingredients in ingredient class “Meat Class A” for the ingredients in ingredient class “Meat Class B” between 2020 and 2050. At the end of the policy, only 20 percent of ingredients in “Meat Class A” remain (in relation to BAU). The simulation results of the policy are presented in Figure 6.11.

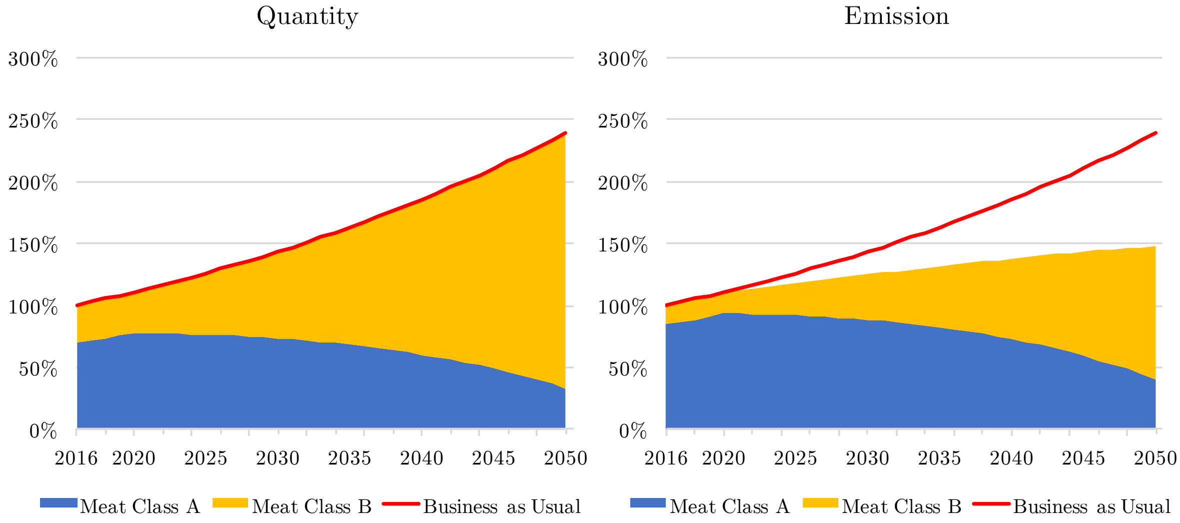


Figure 6.11. Simulation example for steering parameter: Substitute Ingredient Class.

The reduction of emissions, see right graph in Figure 6.11, in relation to BAU can be explained by the overall lower emission factors of the ingredients in “Meat Class B” in relation to the ones in “Meat Class A”. Note that the total quantity in the left graph is the same as BAU.

6.1.2.5 Targeted Sales

This steering parameter allows simulation of policies that would increase future sales of targeted products. It may be used to examine which impact transitions between low and high GHG footprint products would have, e.g. increase sales of plant-based products in relation to meat alternatives. The input parameters for the steering parameter are summarised in Table 6.8.

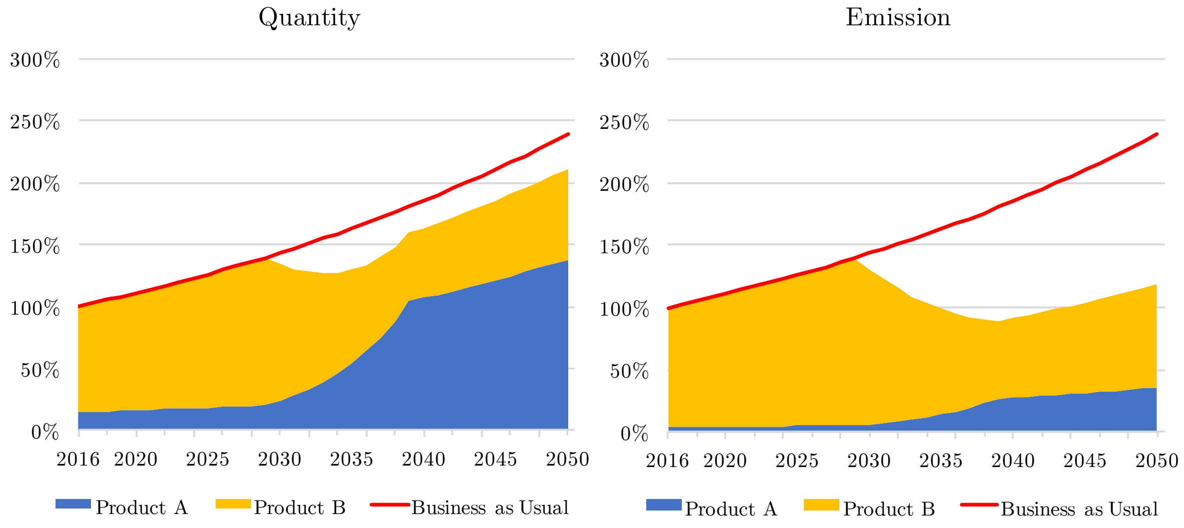
Table 6.8. Input for steering parameter: Targeted Sales.

Parameter	Explanation
Product	The Product the sales is going to be altered.

Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
Change in Sales (%)	The yearly change in sales for the selected Product.

Example

The example below is based on a scenario where sales are targeted towards "Product A" and "Product B". In this scenario, "Product A" is set to increase annually by 15 percent from 2030 to 2040 while Product B decreases at a rate of 10 percent per year for the same period. The simulation results are found in Figure 6.12.


Quantity

Emission

Figure 6.12. Simulation example for steering parameter: Targeted Sales.

Note that the policies for "Product A" and "Product B" are independent of each other but may be used for comparisons, as presented in Figure 6.12. The conclusion of these policies combined may be that the total emissions are significantly lower but so is the total quantity. Therefore, there may be a gap that must be filled from increasing sales of other products (potentially with higher GHG footprint).

6.1.2.6 Altering CO_2 Emission Factor

This steering parameter is similar to the corresponding one for raw material presented in Section 6.1.1.3 Altering CO2 Emission Factor. An important difference is, however, the restriction to only enable steering on the total emission factor. It is therefore up to the user to quantify the increase/reduction of the total emission factor without the liberty to specifically target the extraction or transformation share as in the material steering parameter. The input parameters for the steering parameter are summarised in Table 6.9.

Table 6.9. Input for steering parameter: Altering CO_2 Emission Factor (Food Ingredient).

Parameter	Explanation
Ingredient	The ingredient which emission factor will be affected by the policy
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
Percentage of Change (%)	The percentage of decrease/increase for the affected emission factor at the end of the policy (in relation to the value at "Start Year").

Example

This example decreases the emission factor for "Ingredient A" by 25 percent between 2020 to 2050. The simulation results are presented in Figure 6.13.

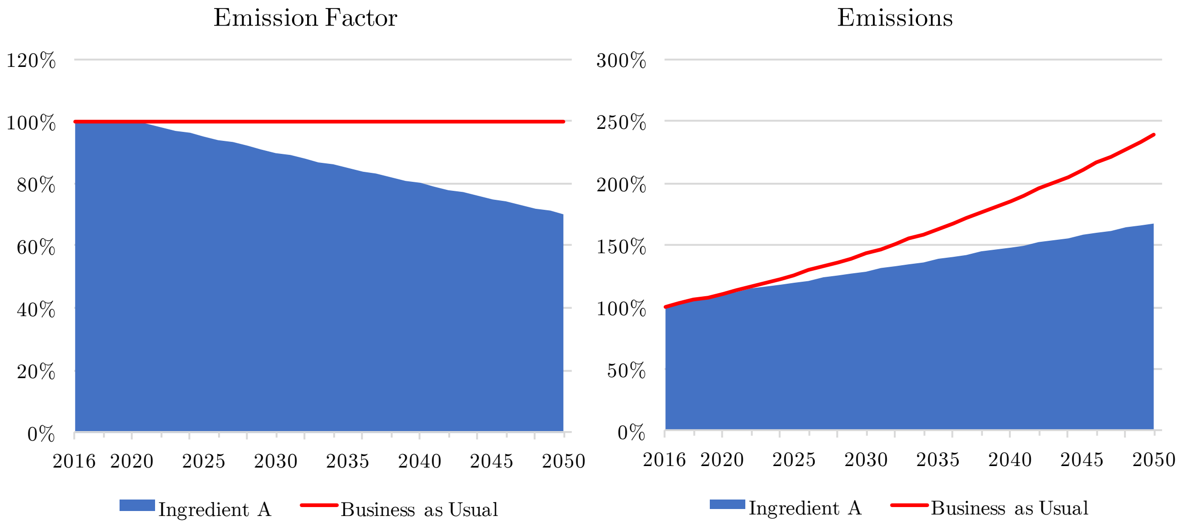


Figure 6.13. Simulation example for steering parameter: Altering CO_2 Emission Factor (Food Ingredient).

The emission reduction seen in the right graph in Figure 6.13 has a perfect positive correlation to the reduction of the emission factor seen in the left graph. The quantity is unaffected by this policy.

6.1.3 Production

This section describes how the steering parameters related to emission area production, presented in Section 5.3.3 Steering Parameters, are implemented in the simulation tool. They are based on the GHG inventory and calculation methodology presented in Section 4.2.3 Production Footprint.

6.1.3.1 Energy Efficiency

This setting allows the user to evaluate the implications of improving the energy efficiency of suppliers. By improving the energy efficiency, all energy areas affected by the policy and contributing to total emissions will decrease. The input parameters for the steering parameter are summarised in Table 6.10.

Table 6.10. Input for steering parameter: Energy Efficiency (Production).

Parameter	Explanation
Unit	The affected Unit(s).
Category Area	The affected Category Area(s).
Main Category	The affected Main Categor(y/ies).
Segment	The affected Segment(s).
Continent	The affected Continent(s).
Country	The affected Countr(y/ies).
Exception(s)	Unit(s), Category Area(s), Main Categori(y/ies), Segment(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Energy Source	The affected energy source(s). (These refer to Electricity, Internal Transport and Production & Building).
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as “Start Year” which would imply that the policy is completely implemented the same year as it is started.)
Energy Efficiency (%)	The energy efficiency achieved at the end of the policy.

Example

This example improves the energy efficiency for all suppliers in Unit A located in Asia, except for Category Area A suppliers, up to 40 percent from 2020 to 2050. The simulation outcomes are presented in Figure 6.14.

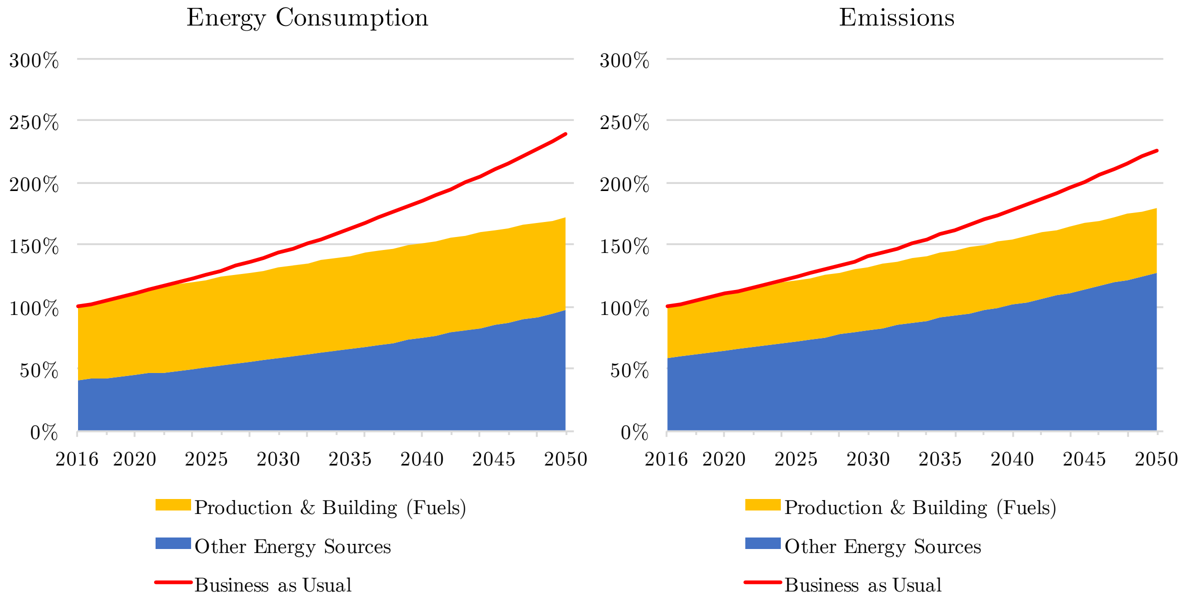


Figure 6.14. Simulation example for steering parameter: Energy Efficiency (Production).

Note that the results presented in Figure 6.14 include all energy sources for all suppliers in Unit A located in Asia (except for Category Area A). Since the policy is targeted at production and building (fuels) only, other energy sources follow the BAU scenario. As can be seen, when comparing the baselines, the energy consumption is higher for production and building (fuels) than other energy sources, see the left graph. However, the corresponding relationship for the emissions is the opposite, see the right graph. The emission intensity for energy consumption is, therefore, higher for energy sources than production and building (fuels). This explains why the total energy consumption reduction is at a higher rate than the corresponding one for total emissions. An insight that could aid decision makers to identify other focus areas for additional policies.

6.1.3.2 Substitute Energy Fuel Source

In similarity to the corresponding steering parameters for raw material (presented in Section 6.1.1.1 Substitute Material) and food ingredients (presented in Section 6.1.2.3 Substitute Item and Section 6.1.2.4 Substitute Ingredient Class), this steering parameter is used for substitution between energy sources. It allows the user to evaluate policies where suppliers fulfil their energy demand from alternative sources, e.g. switching from fossil fuels to biofuels. The input parameters for the steering parameter are summarised in Table 6.11.

Table 6.11. Input for steering parameter: Substitute Energy Fuel Source.

Parameter		Explanation
Unit		The affected Unit(s).
Category Area		The affected Category Area(s).
Main Category		The affected Main Categor(y/ies).
Segment		The affected Segment(s).
Continent		The affected Continent(s).
Country		The affected Countr(y/ies).
Exception(s)		Unit(s), Category Area(s), Main Categori(y/ies), Segment(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Energy Source		The affected energy source(s). (Refers to Internal Transport and Production & Building).
Energy Fuel Source	**From**	The energy fuel source that the energy consumption will be substituted from.
	To	The energy fuel source that the energy consumption will be substituted to.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as “Start Year” which would imply that the policy is completely implemented the same year as it is started.)
New Share (%)		The new share of “Energy Fuel Source (From)” at the end of the policy. The energy demand has been substituted to “Energy Fuel Source (To)”.

Example

This steering parameter phases out natural gas (Energy Fuel Source (From)) starting from 2025 by using biogas (Energy Fuel Source (To)) instead for all suppliers. By 2050, all suppliers affected by the policy will have substituted all natural gas energy consumption (0 percent natural gas at the end of the policy). The simulation results are presented in Figure 6.15.

As can be seen in the right graph in Figure 6.15, the energy consumption of natural gas has been completely phased out and substituted to biogas by 2050. In the right graph, it appears as if the emissions have been completely erased at the end of the policy. There is, however, the share from biogas still present. This corresponds to 0,3 percent (and therefore not visible) compared to the BAU scenario when the energy consumption is fulfilled by natural gas. Evaluation of the policy thereby demonstrates an emission reduction of approximately a factor 340.

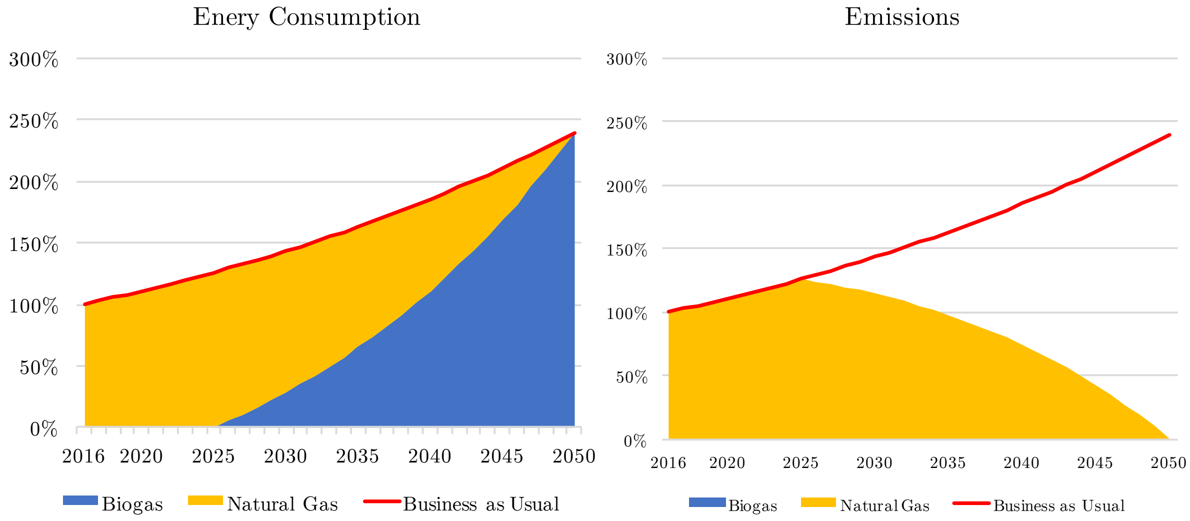


Figure 6.15. Simulation example for steering parameter: Substitute Energy Fuel Source.

6.1.3.3 Renewable Share of Electricity

The steering parameter allows the user to evaluate the policies that change suppliers' renewable share of bought electricity. Suppliers with a higher percentage than specified in the setting will not be affected by the policy (e.g. if Suppler A has a renewable share of 90 percent and the specified setting is set to 80 percent). The input for the steering parameter is found in Table 6.12.

Note that the setting is formulated using the assumption that a 100 percent renewable share of electricity gives a GHG footprint of 0 kg CO_2 eq/kWh. See Appendix B Simulation Tool Calculations for further description and discussion of the assumption.

Table 6.12. Input for steering parameter: Renewable Share of Electricity.

Parameter	Explanation
Unit	The affected Unit(s).
Category Area	The affected Category Area(s).
Main Category	The affected Main Categor(y/ies).
Segment	The affected Segment(s).
Continent	The affected Continent(s).
Country	The affected Countr(y/ies).
Exception(s)	Unit(s), Category Area(s), Main Categori(y/ies), Segment(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
New Renewable Share (%)	The new share of bought renewable electricity.

Example

This example is set to a policy where all suppliers in Sweden will use 100 percent renewable energy by 2040. The renewable share is expected to gradually increase, beginning at 2020. The simulation results are presented in Figure 6.16.

Figure 6.16. Simulation example for steering parameter: Renewable Share of Electricity.

The results from the policy is presented in three graphs; the upper left shows the average renewable shares for the suppliers affected by the policy, the upper right presents their average emission intensity (kg CO_2/kWh) and finally the total emissions of the suppliers are summarised in the graph at the bottom, see Figure 6.16. As the average renewable share increases, the emission intensity decreases due to the lower GHG footprint of renewable electricity. By 2040, at the end of the policy, all suppliers have 100 percent renewable share and thereby an emission intensity of 0 kg CO_2/kWh. This relationship is reflected in the bottom graph where the total emissions of the suppliers are zero at this point. Note that the energy consumption in this policy is stationary, i.e. the same energy demand is met but through different sourcing of the electricity.

Note also that the BAU for the average renewable share and emission intensity are increasing respectively decreasing up to 2050. This is modelled based on the projection of the energy source mix in the European electricity grid up until this point. This is also captured in the BAU for the total emissions, which otherwise would have been higher. More details on this projection are found in Appendix B Simulation Tool Calculations.

6.1.3.4 Refrigerant Spillage Reduction

This steering parameter allows the user to evaluate the implications of reductions of refrigerant spillage. The input parameters for the steering parameter are summarised in Table 6.13.

Table 6.13. Input for steering parameter: Refrigerant Spillage Reduction.

Parameter	Explanation
Unit	The affected Unit(s).
Category Area	The affected Category Area(s).
Main Category	The affected Main Categor(y/ies).
Segment	The affected Segment(s).
Continent	The affected Continent(s).
Country	The affected Countr(y/ies).
Exception(s)	Unit(s), Category Area(s), Main Categori(y/ies), Segment(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
Reduction (%)	The reduction achieved at the end of the policy (in relation to BAU).

Example

By introducing systematic leakage controls for all suppliers starting from 2020, a reduction of 60 percent is estimated to be fulfilled by 2030. The simulation results are presented in Figure 6.17.

As can be seen in the graphs in Figure 6.17 the quantity (left) and emissions (right) follow a perfect positive relationship. At the same rate as the refrigerant quantity decreases, so does the total emissions. Note that the reduction of 60 percent is compared to BAU but when considering the growth factor, the absolute reduction at 2050 compared to baseline is less than 5 percent.

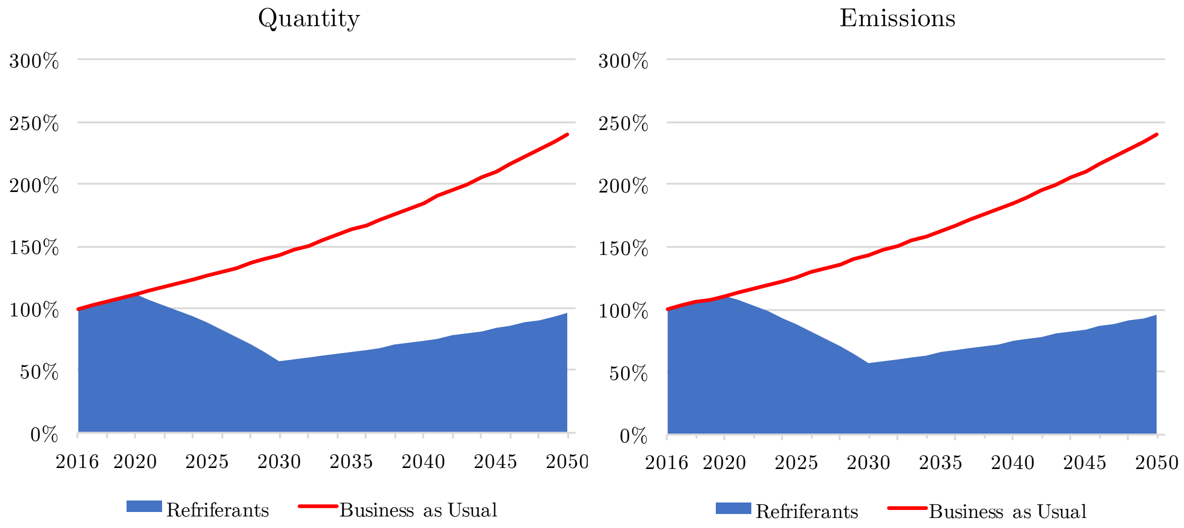


Figure 6.17. Simulation example for steering parameter: Refrigerant Spillage Reduction.

6.1.3.5 Substitute Refrigerants

The steering parameter allows the user to evaluate policies where suppliers substitute refrigerants. The input parameters for the steering parameter are found in Table 6.14.

Table 6.14. Input for steering parameter: Substitute Refrigerants.

Parameter		Explanation
Unit		The affected Unit(s).
Category Area		The affected Category Area(s).
Main Category		The affected Main Categor(y/ies).
Segment		The affected Segment(s).
Continent		The affected Continent(s).
Country		The affected Countr(y/ies).
Exception(s)		Unit(s), Category Area(s), Main Categori(y/ies), Segment(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Refrigerant	**From**	The refrigerant that will be substituted from.
	To	The refrigerant that will be substituted to.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as “Start Year” which would imply that the policy is completely implemented the same year as it is started.)
New Share (%)		The new share of “From Refrigerant” at the end of the policy (in relation to BAU).

Example

This example is set to a policy where all suppliers must phase out (0 percent share at end of policy) Refrigerant A, B and C with high GWPs to a low-value alternative Refrigerant D between 2020 to 2040. The simulation results are presented in Figure 6.18.

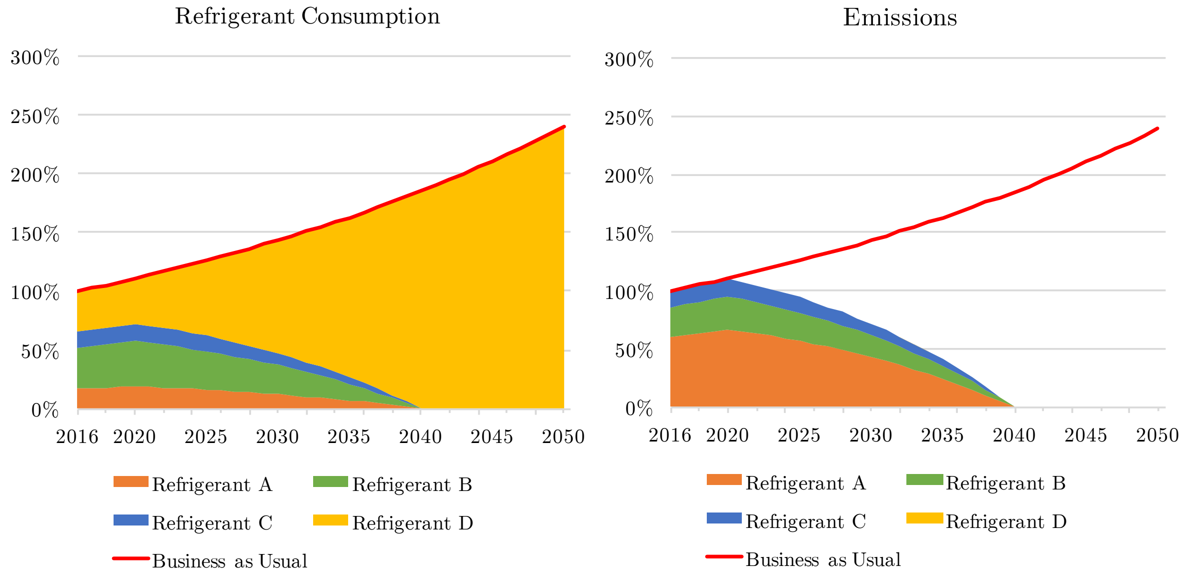


Figure 6.18. Simulation example for steering parameter: Substitute Refrigerants.

The left graph in Figure 6.18 presents the consumption for the four refrigerant types and the right graph shows their corresponding emissions. When comparing the consumption and emissions, it is clear that the emission intensities are significantly different between the refrigerant types. For example, the baseline consumption of “Refrigerant A” is less than 20 percent of the total but accounts for approximately 60 percent of the aggregated emissions. The low impact alternative, “Refrigerant D”, is not represented in the right graph since its GWP potential is zero. When phasing out the other refrigerants and substituting them with “Refrigerant D”, the emissions at the end of the policy is therefore also zero.

6.1.4 Product Use

This section describes how the steering parameters related to emission area product use, presented in Section 5.4.3 Steering Parameters, are implemented in the simulation tool. The steering parameters are based on the GHG inventory and calculation methodology presented in Section 4.2.4 Product Use Footprint.

6.1.4.1 Energy Efficiency

In similarity to the steering parameter for production, presented in Section 6.1.3.1 Energy Efficiency, this steering parameter is used to evaluate policies that relate to energy efficiency. This parameter, however, evaluates the implications of improving the energy efficiencies of products in the product range rather than production. The input parameters for the steering parameter are summarised in Table 6.15.

Table 6.15. Input for steering parameter: Energy Efficiency (Product Use).

Parameter	Explanation
Home Furnishing Business	The affected Home Furnishing Business(es).
Product Area	The affected Product Area(s).
Product Type	The affected Product Type(s).
Continent	The affected Continent(s).
Country	The affected Countr(y/ies).
Exception(s)	Home Furnishing Business(es), Product Area(s), Product Types(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
Energy Efficiency (%)	The energy efficiency achieved at the end of the policy (in relation to BAU).

Example

This example simulates a scenario where the energy efficiencies for all products in "Product Area A" improves up to 30 percent between 2020 to 2040. Simultaneously, products in "Product Area B" are expected to improve up to 50 percent between 2020 to 2030, followed by an improvement up to 20 percent between 2030 to 2040. The simulation results are presented in Figure 6.19.

As can be seen from the graphs in Figure 6.19, the same percentage of reduction is achieved for the total energy consumption (left) and emissions (right). The improvement for "Product Area A" is consistent during the policy period. However, due to the split policy periods for "Product Area B", a slight change in trend may be read at 2030 as the energy efficiency improvements abate in relation to the 2020 to 2030 projection. This feature may be useful when great improvements are projected due to new technology. In many scenarios, it may also be useful to evaluate the implications if these improvements wear off as time progress.

Note that the BAU is based on the same assumption for the projection for the electricity grid mix as presented in Section 6.1.3.3 Renewable Share of Electricity, giving the total emission trajectory a slightly lower increase. See Appendix B Simulation Tool Calculations for further description.

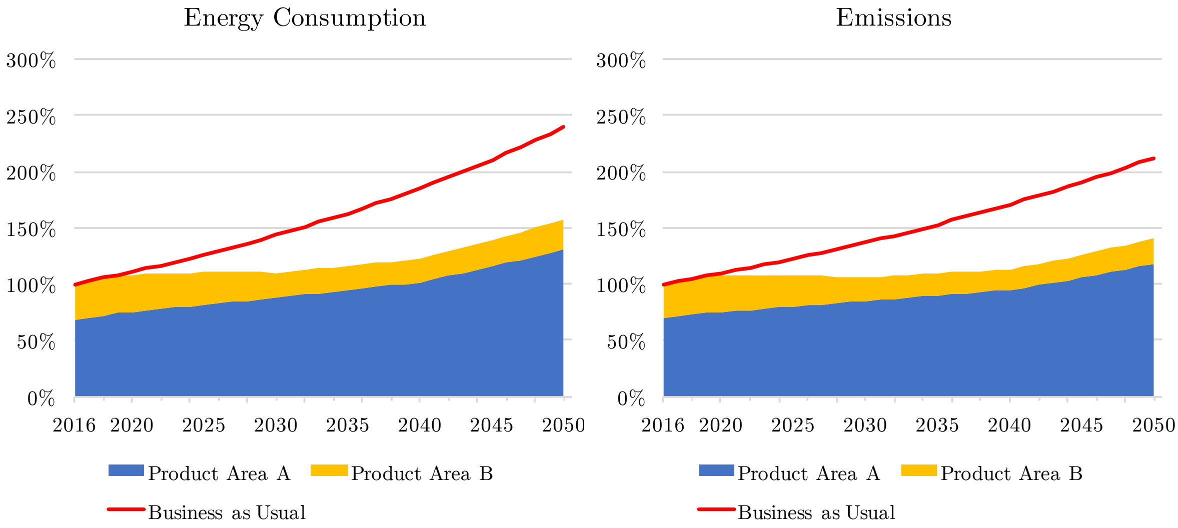


Figure 6.19. Simulation example for steering parameter: Energy Efficiency (Product Use).

6.1.4.2 Substitute Product Types

This steering parameter allows the user to evaluate the effects of substituting product types that fulfil the same function but has different energy efficiencies and/or technologies, affecting their GHG footprint differently. Input parameters for the steering parameter are summarised in Table 6.16.

Table 6.16. Input for steering parameter: Substitute Product Types.

Parameter		**Explanation**
Home Furnishing Business		The affected Home Furnishing Business(es).
Product Area		The affected Product Area(s).
Product Type	**From**	The Product Type that will be substituted from.
	To	The Product Type that will be substituted to.
Continent		The affected Continent(s).
Country		The affected Countr(y/ies).
Exception(s)		Home Furnishing Business(es), Product Area(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Start Year		The year the policy is planned to start.
End Year		The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as “Start Year” which would imply that the policy is completely implemented the same year as it is started.)
New Share (%)		The new share of “From Product Type” at the end of the policy (in relation to BAU).

Example

This scenario evaluates phasing out “Product Type A” in favour for “Product Type B” and “Product Type C” between 2025 and 2035. At the end of the policy, “Product Type B” accounts for 20 percent of what the “Product Type A” quantity should have been in the BAU scenario. “Product Type C” accounts for the remaining 80 percent. The simulation outcomes are presented in Figure 6.20.

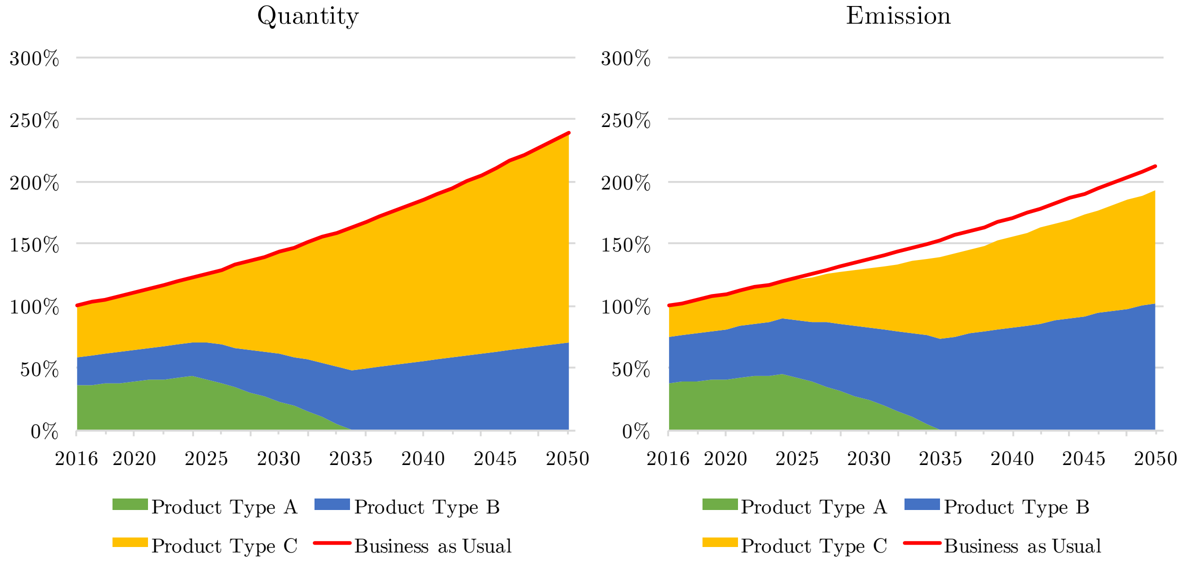


Figure 6.20. Simulation example for steering parameter: Substitute Product Types.

As can be seen in the right graph in Figure 6.20, the total emissions have decreased slightly from the policy while the total quantity remains at the same level as BAU, see the right graph. However, the distribution of product types is different with the highest share of “Product Type A” being substituted to “Product Type C”. Even though “Product Type B” only accounts for roughly 30 percent of total product at the end of the policy, they make up approximately half of the emissions. Evaluation of the policy may, therefore, conclude that it would be more beneficial to phase out “Product Type A” exclusively to “Product Type B” as it has a lower emission intensity than “Product Type C”.

6.1.4.3 Renewable Share of Combustion Fuel

In correspondence to the steering parameter for production, presented in Section 6.1.3.3 Renewable Share of Electricity, this steering parameter is aimed at alternating the renewable share. However, in this context, the renewable share relates to the share in combustible fuels. The input parameters needed to allow the user to evaluate the policies that change the renewable share are found in Table 6.17.

Table 6.17. Input for steering parameter: Renewable Share of Combustion Fuel.

Parameter	Explanation
Home Furnishing Business	The affected Home Furnishing Business(es).
Product Area	The affected Product Area(s).
Product Type	The affected Product Type(s).
Continent	The affected Continent(s).
Country	The affected Countr(y/ies).
Exception(s)	Home Furnishing Business(es), Product Area(s), Product Types(s), Continent(s) and/or Countr(y/ies) to exclude from the policy.
Start Year	The year the policy is planned to start.
End Year	The year the policy is planned to be completely fulfilled. (This parameter could be set to the same as "Start Year" which would imply that the policy is completely implemented the same year as it is started.)
New Renewable Share (%)	The renewable share of the combustion fuel achieved at the end of the policy (in relation to BAU).

Example

This example increases the renewable share of product area "Candles" gradually up to 75 percent between 2020 to 2030, followed by an increase up to 100 percent from 2030 to 2050. The simulation results are presented in Figure 6.21.

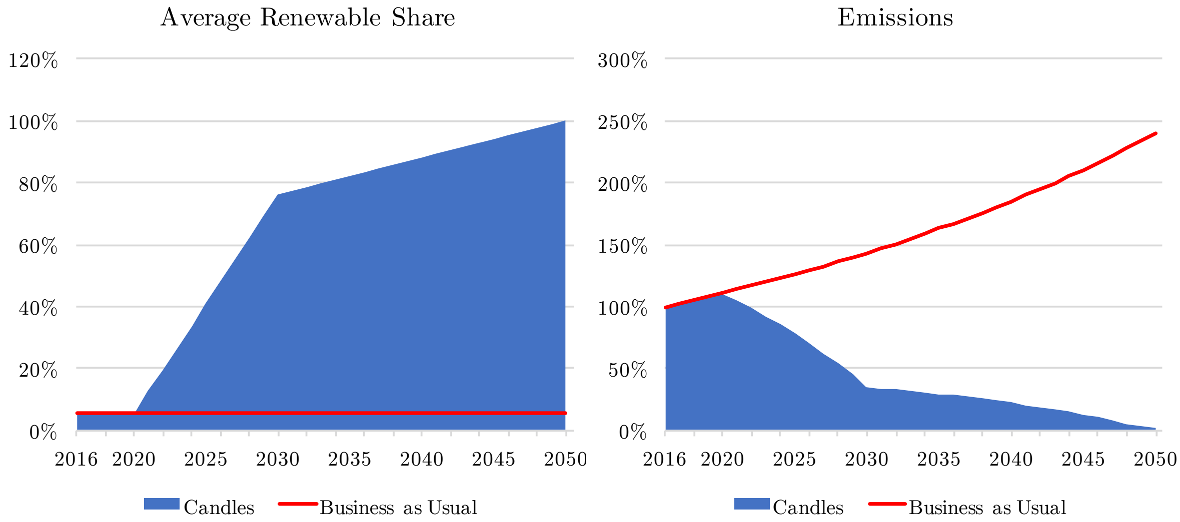


Figure 6.21. Simulation example for steering parameter: Renewable Share of Combustion Fuel.

In the right graph in Figure 6.21, the average renewable share for product area "Candles" are presented. In conformity with the defined scenario, the renewable share increases from its BAU level up to 75 percent between 2020 and 2030, followed by an increase up to 100 percent by 2050. The corresponding emissions relating to this scenario are found in the right graph. When the renewable share increases, the emissions decrease at the same rate. The remaining emissions at the end of the policy (less than 1 percent compared to business as usual) are due to the renewable material having an emission intensity marginally bigger than zero (due to other GHG gases than CO_2).

6.1.5 Combination of Scenarios and Steering Parameters

As discussed in the introduction to the steering parameters, the result of several isolated policies does not always aggregate up to the same outcome when combining them. There are commonly overlaps of different policies, e.g. between the examples presented in Section 6.1.1.1 Substitute Material, Section 6.1.1.2 Lightweight Solution and Section 6.1.1.3 Altering CO2 Emission Factor. Simultaneously as the materials are substituted, the lightweight reduction policy must be captured so that the overall emission reductions may be assessed accurately. In Figure 6.22, all examples are combined in one simulation to show the outcome of combining scenarios.

The conclusion to draw from the result presented in Figure 6.22 is primarily that the combined policy simulation differs from the cumulative results from the isolated simulations. To further depict this, Figure 6.23 shows the accumulated reductions (in relation to BAU) for the isolated simulations marked in blue colours and the combined simulation in red. For these specific scenarios, the total reduction is more than 6 percentage points higher for the isolated simulations in comparison to the combined simulation.

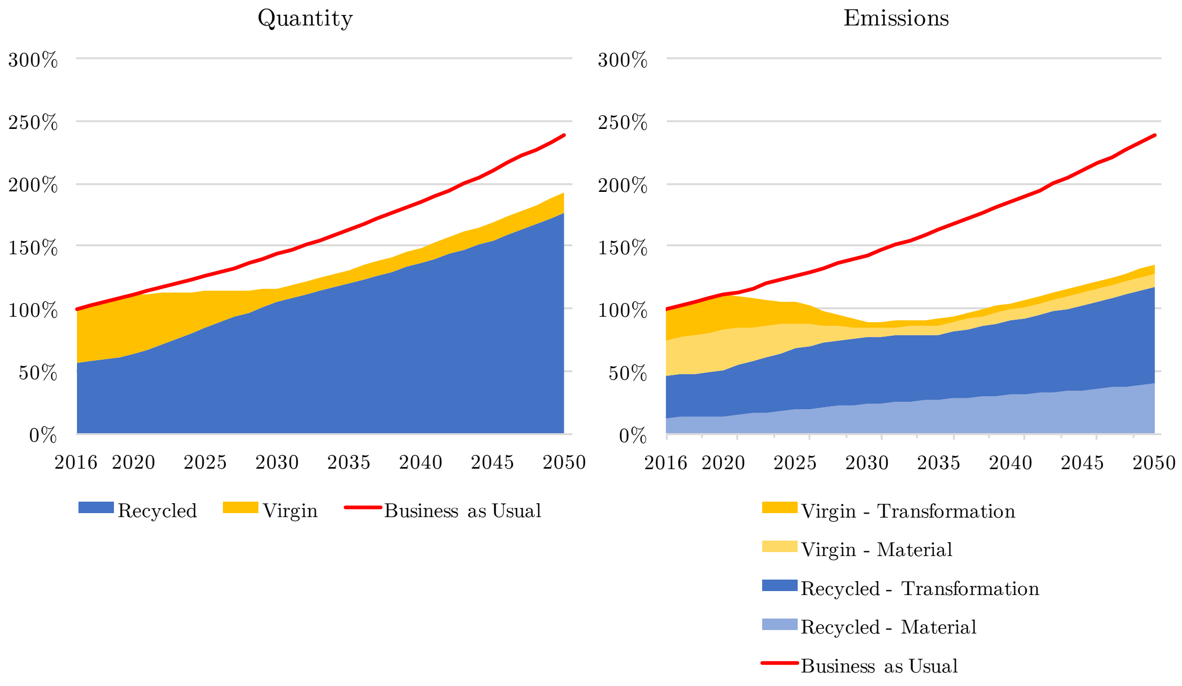


Figure 6.22. Simulation example for the combination of scenarios and steering parameters.

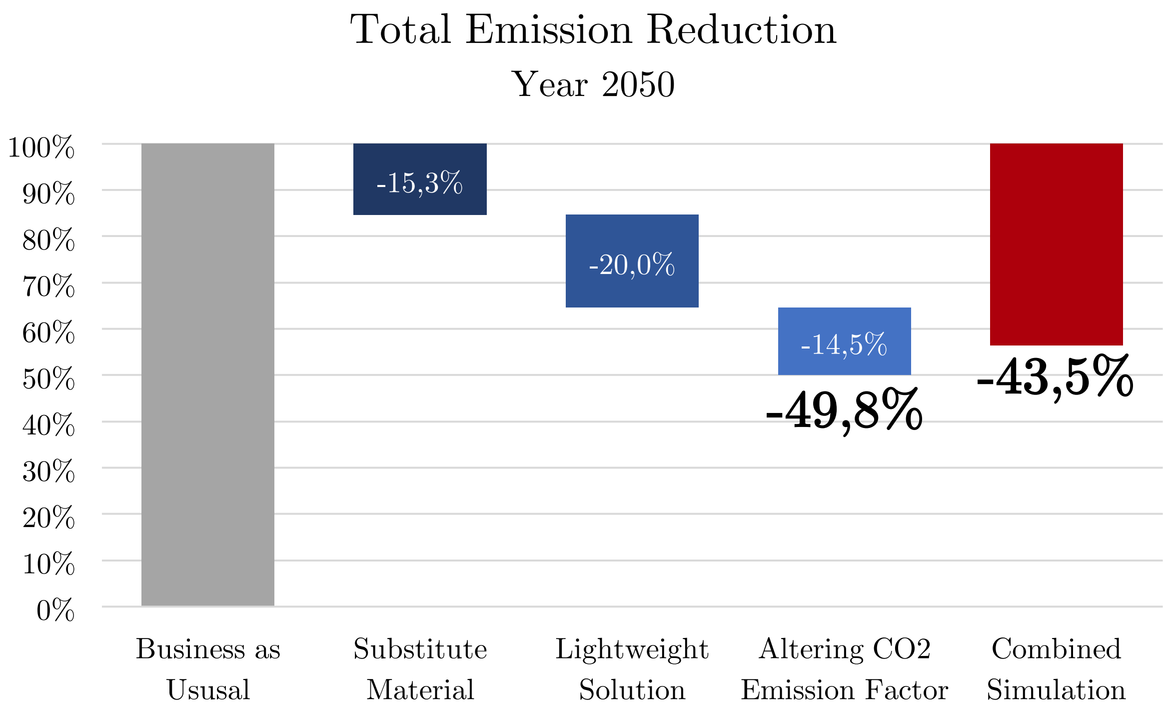


Figure 6.23. The difference between isolated simulations and combined simulation.

When examining the system at a more holistic level, an aggregated representation facilitates evaluation of the combined impact of policies for different emission areas. Figure 6.24 and Figure 6.25 presents examples of such representations. The influence from the emission areas is cumulated and presented in relation to the aggregated BAU scenarios.

One of the requirements for the simulation tool was to support evaluation on different time horizons. Figure 6.24 shows the mid-term and Figure 6.25 the long-term impacts of the formulated policies. Ponder that the mid-term targets are to decrease absolute emissions with 10-20 percent. To visualise the current state of policies, these trajectories are plotted in the graph. The result of the simulation shows that the formulated policies are in line with the 10 percent target.

However, when looking at the long-term time horizon in the long-term graph, they are not sufficient to fulfil the SBT requirements of 41-72 percent absolute reductions by 2050. This kind of visualisation facilitates gap analysis and communicates which emission areas extra consideration must be focused on. Additionally, the overview visualisation supports decision making when determining which ambition level the climate targets should be formulated on, e.g. if targets should aim for the 41 or 72 percent absolute reduction.

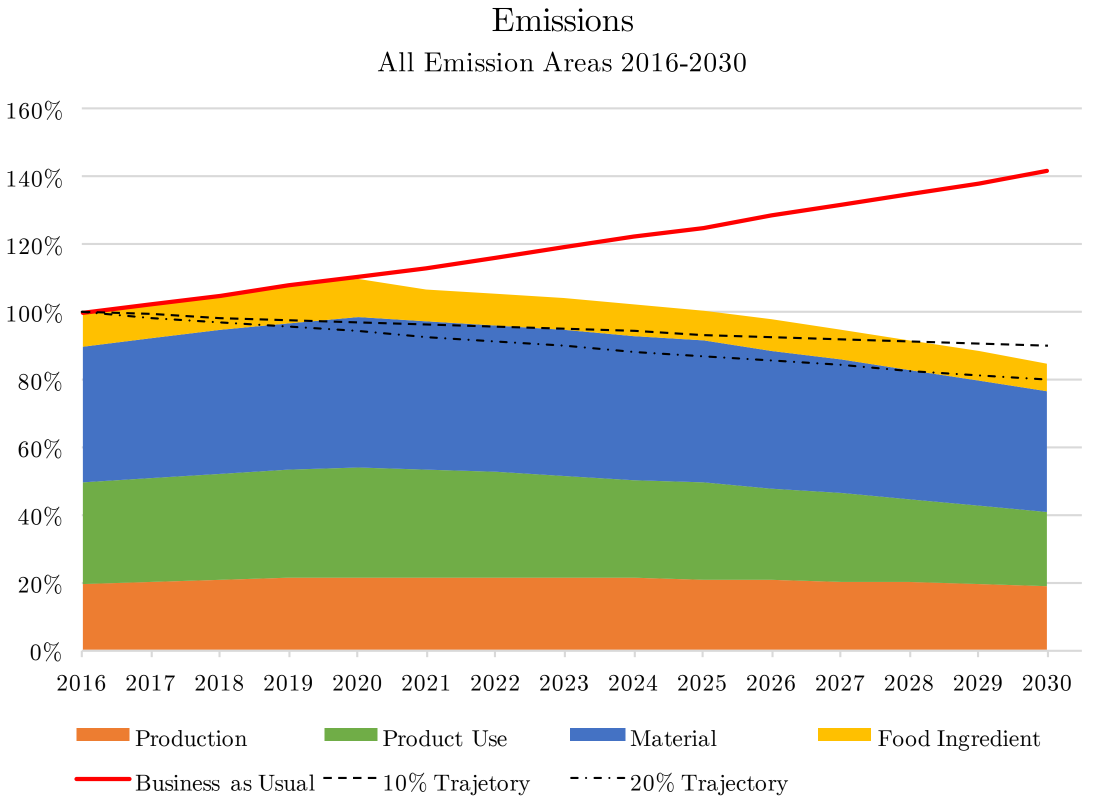


Figure 6.24. All emission areas aggregated: Mid-term 2016-2030.

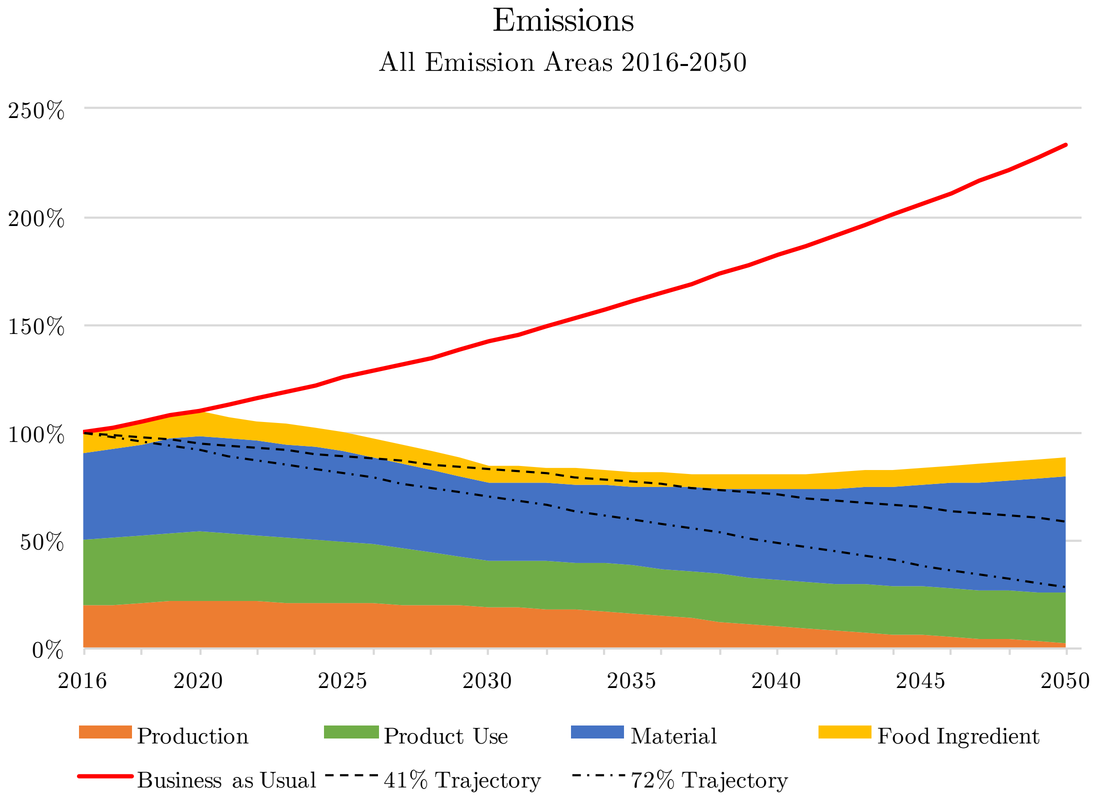


Figure 6.25. All emission areas aggregated: Long-term 2016-2050.

6.2 Testing

Testing of model logic and calculations was conducted through all steps of the system dynamics modelling process in order to ensure a high confidence among everyone in the project team. The VV&T techniques used are presented in the following sections.

Informal VV&T Techniques

Desk checking was constantly performed by the author not working with the logic and coding of the model to avoid bias. Furthermore, results and new scenarios were constantly reviewed as a form of face validation by concerned entities of the project team to judge the feasibility. If something was deemed incorrect, a meeting was held to discuss the logic and calculations used to figure out what might have gone wrong and find solutions. A new meeting was then held to present the new results. This was an iterative process that went on until feasible results were achieved. Lastly, the modelling process was documented and sent out to the project team as a preview. The documentation was then discussed during various workshops in order to both achieve transparency but also raise discussion about the logic.

Static VV&T Techniques

As the model is a hybrid of system dynamics and spreadsheet modelling, syntax analysis was carried out by Excel's programming language Visual Basic Advanced (VBA). Furthermore, consistency checking was carried out to ensure that the cosmetic style of variables and the manipulation of data elements were consistent.

Dynamic VV&T Techniques

Debugging and symbolic debugging was constantly performed on the code, the debugger of VBA helped the modellers to locate and address problems encountered. Sensitivity analysis was performed to see how the model behaved with input parameters that were deemed unfeasible. If the behaviour was unsatisfying, the modellers made an attempt to address the issue. All issues that could not be solved because of the dynamic of the system was documented to notify end users.

Formal VV&T Techniques

All calculations implemented in the code was presented to the project group as mathematical notations during workshops. The mathematical notations were then implemented in a separate spreadsheet in Excel. By applying the same input parameters in the mathematical notations as were used in the model, the results of the model could be validated.

7 Discussion of the Simulation Tool

This chapter sheds light on the benefits and limitations of the simulation tool to enhance understanding of its potential use in other contexts and environments. Furthermore, future recommendations for improvement are suggested to urge succeeding research to focus on areas of interest.

7.1 Benefits

There are multiple benefits of using the simulation tool when setting climate targets, especially in the context of SBT. A prerequisite for climate targets to be “science-based” are that they are formulated using as much and as accurate facts as possible. The simulation tool facilitates such an approach. Evaluation of policies through the simulation tool gives an indication of whether the proposed targets are sufficient to fulfil the requirements defined by the SBTi. Furthermore, the simulation tool allows for a flexible and iterative approach to the formulation of climate targets. If initial policies are insufficient when meeting the requirements, new policies may be formulated, simulated and evaluated within a relatively short time frame. This allows for a higher degree of freedom when exploring the Scope 3 emission system, making it more accessible when identifying focus areas and assessing the impacts of various policies.

Another benefit of the simulation tool is that it captures the possibility of overlap and conflicting policies as seen in Section 6.1.5 Combination of Scenarios and Steering Parameters. This example shows that neglecting the possibility of overlap when several policies are combined entail the risk of leading to too optimistic projections of emission reductions. Using the simulation tool mitigates this risk since the sequential and combinatorial order of the steering parameters is considered. When policies are formulated in a decentralised manner, e.g. policy input from several business units, the aggregated result of the policies may be summarised in one simulation to evaluate the overall picture. However, the methodology for simulations of isolated policies may serve as a good introduction when exploring the Scope 3 emission system and to identify focus areas, i.e. finding policies with greater impact than others.

The high level of detail that is allowed for policy evaluation in the simulation tool is also an advantage. The simulation tool is formulated using the highest level of detail in data available as it permits the highest degree of freedom for steering. In combination with the different time horizons that can be considered, climate targets can be formulated on a strategic, tactical as well as on an operational level. A top-down approach could be applied when formulating long-term climate targets at an aggregated level. When different emission areas and/or business units need to concretise these targets for their specific function or operations, the simulation tool could be applied at this level as well. In fact, it is possible to formulate specific climate targets for suppliers (production) or specific products (food ingredient).

Lastly, the environment the simulation tool is implemented in facilitates a greater reach among potential users. Since spreadsheet software, especially Excel, is a widely used platform for data analysis, the simulation tool is more accessible than it would have been in a specialised simulation software. This is essential in order to fully take advantage of the flexibility of the tool, allowing it to be used on a strategic as well as on an operational level. Furthermore, the platform enhances the possibility of further development and implementation of new steering parameters as they are identified. Adjustments may be done as new insights of the Scope 3 emission system are gained. When new data becomes available or if the data granularity is improved, it could be implemented in the tool parallel to updating the calculation methodology for the GHG inventory.

7.2 Limitations

In contrast to the multiple benefits of the simulation tool, there are multiple limitations which are important to address as well. A fundamental limitation of the tool is that it disregards any stochastic behaviour in the Scope 3 emission system. Furthermore, any uncertainties in the GHG inventory and input parameters are not considered in the simulations. Any results that the simulation tool produces should, therefore, be used as rough approximations and seen as guidance rather than being the sole deciding factor to consider when formulating climate targets. The simulation tool is aimed to support stakeholders to explore and gain insights of the Scope 3 emission system, not to serve as an exclusive decision basis.

Secondly, the simulation tool does not consider the full scope of the value chain in the Scope 3 emission system. The various emission areas are, in many ways, treated isolated where the influences and interrelationships between them are neglected. Transportation is one of these crucial elements that is excluded from the simulation tool. To fully capture the dynamics of the system, all emission areas and the scoped-out elements must be included. Policies might overlap and influence each other in more ways than what was considered during the formulation of the simulation tool.

The user interface of the simulation tool is another area that needs to be addressed as a limitation. Due to the time constraint of the project as well as continuous requests of updated functionalities to be implemented in the simulation tool, the usability of the tool is lacking a user-friendly and intuitive interface. Early versions of the tool included functionality that guided the user through the various steering parameters with predefined graphs of interest for the specific parameter. However, as the complexity of the tool evolved with new features and steering parameters, priority was set on verification, validation and testing of these rather than an intuitive user experience. A great limitation of the current version is, therefore, the reduced usability.

Furthermore, the short-term projections in the simulation tool are based on the same calculations and assumptions as the mid- and long-term. A limitation is therefore that the short-term projections disregard more precise historical data and trends. More accurate short-term forecasts could be implemented in the tool through statistical analysis of the GHG inventory from previous years. When evaluation policies on this time horizon, the credibility of the simulated results would increase significantly.

7.3 Future Recommendations for Improvement

As previously mentioned, a critical limitation of the simulation tool is the lack of probabilistic variables. A simple solution, but still not addressing the stochastic behaviour, is to calculate the upper and lower bounds of the simulation. This would visualise the uncertainties of the simulation results. Consideration should then be taken to any uncertainties in the baseline GHG inventory. Projections of the upper and lower bounds would then be reflected as a range in the simulated result. Another approach is to implement Monte Carlo simulation into the spreadsheet model. In contrast to the deterministic upper and lower bounds, this method provides a narrower range of results as it puts less weight on low probabilistic regions. However, this method would put higher requirements on data accuracy and granularity in order to be fully beneficial. Analysis of historical data is likely to provide such details and would be especially useful for short-term policy evaluation.

The scope of the simulation tool is, as discussed as a limitation for the current version. Therefore, it is relevant to consider expanding the scope in order to more accurately predict the behaviour of the Scope 3 emission system. Efforts in this area should be set on expanding the identified emission areas and more comprehensively map their interrelationships and capture potential feedback loops in the system. The drivers of circular economy is an example where further investigation would facilitate a more holistic and dynamic approach to be integrated into the simulation tool. Not only would this expand the scope of emission categories in the value chain, but more consideration would also be set on their dependencies.

Another potential area to improve in the simulation tool is to develop a more sophisticated way of identifying policies with the highest impact. In this sense, the graphical representation presented in Figure 6.23 would be useful for policy evaluation. Even if policies may overlap, some are likely to have a higher overall impact than others. If clearer visualisation of said policies were facilitated, stakeholders could identify focus areas more easily and concentrate their efforts on policies with high impact. Another dimension to consider is the level of influence the company has over the emission drivers through the steering parameters. If one policy proves to have a very high impact, but there are limited possibilities for actually influencing the emission driver, this could also be captured in the simulation tool as influence versus impact diagrams. Said diagrams could potentially aid the decision-making process and put the focus on policies with a high level of impact and influence.

The interface of the simulation tool has an obvious potential for further improvements. In order to fully utilise the benefit of being compatible with a wide range of end users, the simulation tool must be further developed with a focus on their specified needs. These needs and requirements have to be thoroughly analysed to ensure that the simulation tool becomes more accessible. The current version has many of the cornerstones needed, e.g. high level of detail for the steering, in order for it to become usable on a more tactical and operational level. However, the lack of an intuitive interface is a barrier that needs to be developed before this may be enabled.

8 Conclusion

In this chapter, the findings and conclusion of this research are presented to answer the research questions connected to the purpose of the study. The research questions are answered in their order of their appearance, followed by a concluding discussion and suggestions for further studies.

The purpose of this master's thesis was to "develop a simulation tool to support the process of setting climate targets with respect to indirect emissions resulting from value chain activities". In order to do so, research regarding the relevant drivers of Scope 3 emissions had to be conducted. As this thesis focused on the two Scope 3 emission categories; purchased goods and services, and use of sold products, drivers outside of the scope were not included. The research was a combination of conducting workshops with people of expertise in the area and an extensive literature review. Thus, allowing the authors to conduct a gap analysis to identify drivers that potentially were missed during the workshops.

8.1 Which are the emission drivers relating purchased goods and services, and use of sold products in IKEA's Scope 3 emission system?

A finding from the gap analysis is that the major drivers of Scope 3 emission systems are known both at IKEA and in literature as no major gaps were discovered. However, even if said drivers are commonly known, some had to be excluded as it was deemed hard to quantify the impact due to lack of data and assessments. Thus, the importance does not lie in only identifying the drivers but also assessing and quantifying influence and impact. Nevertheless, a categorisation of all relevant drivers is still of importance to enhance communication and understanding of the Scope 3 emission system. The identified drivers, and the answer to the first research question, are found in Table 8.1.

Table 8.1. Emission areas and appurtenant emission drivers.

Emission Area	Emission Drivers
Raw Material	High and Low-Value Materials Resource Efficiency
Food Ingredients	High and Low-Value Ingredient Alternative Resource Efficiency Food Consumption Behaviour
Production	High and Low-Value Energy Sources Renewable Share of Electricity Energy Efficiency Leakage of Refrigerants High and Low-Value Refrigerant Alternative
Product Use	Energy Efficiency Renewable Share of Electricity High and Low-Value Fuel Alternative

8.2 Which parameters can be applied to allow steering on the emission drivers?

To answer the second research question, a mapping of all interrelations and influences throughout the system had to be done. Stock and flow diagrams were applied to identify and communicate parameters for steering on the identified drivers. These parameters are summarised in Table 8.2.

Table 8.2. Emission areas and appurtenant steering parameters.

Emission Area	Steering Parameters
Raw Material	Substitute Material Lightweight Solutions Altering CO_2 Emission Factors
Food Ingredients	Relative Share of Item in Product Range Re-engineering Substitute Item Substitute Ingredient Class Targeted Sales Altering CO_2 Emission Factor
Production	Energy Efficiency Substitute Energy Source Renewable Share of Electricity Refrigerant Spillage Reduction Substitute Refrigerant
Product Use	Energy Efficiency Substitute Product Type Renewable Share of Combustion Fuel

The data granularity among the various emission areas played a significant role when identifying steering parameters, if relevant data are missing, so is the option to steer on the specific driver. However, steering parameters have also been developed to allow the user to quantify the impact themselves. Thus, making it possible to steer on drivers without a pre-defined steering parameter and utilising the specific system knowledge of the user. For instance, the added energy consumption in production due to refrigerant leakage was deemed hard to quantify. However, the user can combine the steering parameters “Refrigerant Spillage Reduction” and “Energy Efficiency” to perform own quantification of the outcome.

8.3 How should a simulation tool be designed to address and capture the behaviour and characteristics of the emission drivers in the Scope 3 emissions system?

The third research question was answered by designing a simulation tool for IKEA to support the process of setting SBTs. The framework for the simulation tool consisted of five ingoing factors; (1) requirements, (2) emission drivers and steering parameters, (3) GHG inventory, (4) scenarios and policies, and (5) the business as usual scenario. The requirements, formulated by IKEA, were important to consider in order to assure that the simulation tool design and functionality really fulfil its purpose of supporting policy evaluation in the target setting process. Furthermore, potential scenarios and policies of stakeholder interest were also mapped during the tool formulation phase to avoid misinterpretations of the requirements. The identified emission drivers and steering parameters from answering the first two research questions, served as the outline when implementing the actual functionality in the simulation tool. The GHG inventory was used to form the baseline as well as to assure that the implemented simulation logic used the same calculation methodology. To fulfil the requirement of policy evaluation, the business as usual scenario was calculated using the baseline GHG inventory and projected future growth.

A benefit of the simulation tool is that it facilitates an iterative, flexible and fact-based approach for setting climate targets. The risk of too optimistic projections of emission reductions is also mitigated since consideration to policy overlap is considered. Furthermore, is the potential reach of end-user an advantage as it is developed using a high level of data detail in an accessible software platform. However, the deterministic behaviour of the simulation tool entails that it disregards any stochastic behaviour of the system and, thus, is limited to only produce one scenario for policy evaluation. The, relatively, narrow scope of the full emission system captured in the simulation tool also reduces its reliability in predicting the system behaviour. Furthermore, the lack of an intuitive interface is a great barrier for end users with no previous experience of the simulation tool.

8.4 Concluding Discussion

The simulation tool has been developed to support the climate target setting process at IKEA. For this reason, the tool has fulfilled its purpose and proven to be valuable for decision-makers when evaluating which ambition level to strive for when setting the climate targets. The primary application area has been at a strategic level with focus set on the mid-term time horizon. The use of the simulation tool has enabled project stakeholders to gain insights of the Scope 3 emission system, not only through policy evaluation but also during the course of its development while mapping the emission drivers and identifying steering parameters. Therefore, when assessing the simulation tool, the complete modelling process should be taken into consideration.

Many characteristics of the tool that is highly specified for the particular setting it is developed in which limits its applicability in other environments. The suggested framework for the factors to consider when developing a simulation tool to support the process of setting climate target is, however, general. The simulation approach that has been applied in this research is, therefore, in many senses, highly generalizable and formulated to be adaptable in other contexts.

Therefore, the theoretical contribution of this master's thesis is the extension of research within the area of sustainability simulation, with especial focus on simulation for setting climate targets. The suggested simulation approach combines the qualitative benefits of system dynamics for the system investigation together with the high flexibility of implementation into a spreadsheet model. The framework could be applied to other companies in their process of setting climate targets in line with SBT. Furthermore, the analysis of the emission drivers and steering parameters in this research could be of interest for said actors as they are formulated in a general manner.

8.5 Future Research

As discussed earlier, there are limitations to the simulation tool that may be addressed in future research. Firstly, the introduction of probabilistic simulation in the tool is an area of a great potential for further studies. The focus should be set on more extensive analysis of the GHG inventory data where mapping of probability distributions of the variables would facilitate stochastic modelling and, ultimately, more credible simulation results.

As this research is scoped to only encompass two of the fifteen Scope 3 emission categories, there is a lot of potentials to extend research to address the other categories. Not only would this shed light on emission drivers and steering parameters in these categories, but would also facilitate a better understanding of the Scope 3 emission system. This would pave the way for studying the system more holistically, allowing for more accurate mapping of the influences and interrelationships between the system elements.

The usability of the simulation tool is another area of interest to focus succeeding research upon. In order to fully utilise the extensive spectrum of potential end users, their needs and requirements must be studied to a higher extent than in this research. By collecting feedback from end users, more tactical and operational functionality could be developed. These insights could be used to improve navigation in the tool where the interface is adapted for policies of interest for the specific user.

In addition to this, more dimensions to the simulation tool than solely the GHG footprint could be studied. Further research may be targeted at extending the ecological aspect by including a wider scope of environmental impacts. However, additional studies may address policy evaluation in the economic and social dimensions. If consideration is taken to said areas, policy and decision makers have more facts on hand which could create incentives for more sustainable investments.

References

Journal Articles

Ardente, F. and Mathieux, F. (2014). Identification and assessment of product's measures to improve resource efficiency: the case-study of an Energy using Product. *Journal of Cleaner Production*, 83, pp.126-141.

Balci, O. (1994). Validation, verification, and testing techniques throughout the life cycle of a simulation study. *Annals of Operations Research*, 53(1), pp.121-173.

Balci, O. (2001). VERIFICATION, VALIDATION AND TESTING OF MODELS. *Encyclopedia of Operations Research & Management Science*, pp. 870-878.

Bergman, R., Puettmann, M., Taylor, A. and Skog, K. (2014). The Carbon Impacts of Wood Products. *Forest Products Journal*, 64(7-8), pp.220-231.

Bergold, J. and Thomas, S. (2012). Participatory Research Methods: A Methodological Approach in Motion. *Historical Social Research / Historische Sozialforschung*, 37(4), pp.191-222.

Boone, T., Jayaraman, V. and Ganeshan, R. (2012). *Sustainable supply chains.* 1st ed. New York: Springer.

Borshchev, A. and Filippov, A. (2004). From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools. In: *The 22nd International Conference of the System Dynamics Society.*

Garnett, T. (2011). Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)?. *Food Policy*, 36, pp.S23-S32.

Gibbert, M., Ruigrok, W. and Wicki, B. (2008). What passes as a rigorous case study?. *Strategic Management Journal*, 29(13), pp.1465-1474.

Jackson, T. (2005). Live Better by Consuming Less?: Is There a “Double Dividend” in Sustainable Consumption?. *Journal of Industrial Ecology*, 9(1-2), pp.19-36.

Koronaki, I., Cowan, D., Maidment, G., Beerman, K., Schreurs, M., Kaar, K., Chaer, I., Gontarz, G., Christodoulaki, R. and Cazauran, X. (2012). Refrigerant emissions and leakage prevention across Europe – Results from the RealSkillsEurope project. *Energy*, 45(1), pp.71-80.

Kuo, T., Chen, H., Liu, C., Tu, J. and Yeh, T. (2014). Applying multi-objective planning in low-carbon product design. *International Journal of Precision Engineering and Manufacturing,* 15(2), pp.241-249.

Lechtenböhmer, S., Nilsson, L., Åhman, M. and Schneider, C. (2016). Decarbonising the energy intensive basic materials industry through electrification – Implications for future EU electricity demand. *Energy*, 115, pp.1623-1631.

Meredith, J. (1998). Building operations management theory through case and field research, *Journal of Operations Management*, 16 (4), 441-454.

Moon, Y. (2017). Simulation modelling for sustainability: a review of the literature. *International Journal of Sustainable Engineering*, 10(1), pp.2-19.

Napp, T., Gambhir, A., Hills, T., Florin, N. and Fennell, P. (2014). A review of the technologies, economics and policy instruments for decarbonising energy-intensive manufacturing industries. *Renewable and Sustainable Energy Reviews,* 30, pp.616-640.

Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K. and Meinshausen, M. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature,* 534(7609), pp.631-639.

Sathre, R. and Gustavsson, L. (2011). Time-dependent climate benefits of using forest residues to substitute fossil fuels. *Biomass and Bioenergy*, 35(7), pp.2506-2516.

Saud, P., Wang, J., Sharma, B. and Liu, W. (2015). Carbon impacts of hardwood lumber processing in the northeastern United States. *Canadian Journal of Forest Research*, 45(12), pp.1699-1710.

Smith, G. A. (2003). Using integrated spreadsheet modeling for supply chain analysis. *Supply Chain Management: An International Journal,* 8(4), 285-290.

Voss, C., Tsikriktsis, N., Frohlich, M. (2002). Case research in operations management, *International Journal of Operations & Production Management*, 22 (2), 195-219.

Woodruff, R. (2003). Alternative Paths to Marketing Knowledge, *Qualitative Methods Doctoral Seminar,* University of Tennessee.

Books

Arbnor, I. and Bjerke, B. (2009). *Methodology for creating business knowledge.* 3rd ed. Los Angeles, Calif.: SAGE.

Bader, G. and Rossi, C. (2002). *Focus Groups: A Step-By-Step Guide.* 3rd ed. The Bader Group.

Bryman, A., Bell, E. (2011). *Business Research Methods: Canadian Edition.* Oxford University Press.

Checkland, P. (1981). *Systems thinking, systems practice.* 1st ed. J. Wiley.

Coyle, R. (1996). *System Dynamics Modelling.* 1st ed. London: Chapman & Hall.

Denscombe, M. (2010). *The good research guide.* 1st ed. Maidenhead, England: McGraw-Hill/Open University Press.

Jackson, M. (2002*). Systems Approaches to Management.* 1st ed. Boston, MA: Springer US.

Kotzab, H., Suering, S., Müller, M. and Reiner, G. (Eds.) (2005). *Research methodologies in supply chain management.* 1st ed. Heidelberg: Physica-Verlag.

Law, A. and Kelton, W. (2000*). Simulation modeling and analysis.* 3rd ed. New York, NY: McGraw-Hill Education.

Neuman, W. (2014). *Social Research Methods: Qualitative and Quantitative Approaches.* 7th ed. Boston [u.a.]: Pearson.

Ragsdale, C. (2010). *Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Management Science.* 6th ed. Mason, OH: South-Western, Division of Thomson Learning.

Silverman, D. (2015). *Interpreting Qualitative Data.* 5th ed. London: SAGE Publications Ltd.

Sokolowski, J. and Banks, C. (Eds.) (2009). *Principles of modeling and simulation.* 1st ed. Hoboken, NJ: Wiley.

Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World.* 1st ed. Boston [u.a.]: McGraw-Hill Education.

Yin, R. (2009). *Case study research: design and methods.* 4th ed. Los Angeles: SAGE Publications.

Electronic Sources

Bloomberg. (2017). *Ikea Components AB: Company Profile - Bloomberg.* [online] Available at: http://www.bloomberg.com/profiles/companies/4012636z:ss-ikea-components-ab [Accessed 5 Jun. 2017].

Franchisor IKEA. (2017). *Inter IKEA Systems B.V. - Worldwide IKEA franchisor.* [online] Available at: http://franchisor.ikea.com/worldwide-ikea-franchisor/ [Accessed 5 Jun. 2017].

GHG Protocol. (2017). *About the GHG Protocol / Greenhouse Gas Protocol.* [online] Available at: http://www.ghgprotocol.org/about-ghgp [Accessed 5 Jun. 2017].

IEA. (2017). *Scenarios and projections.* [online] Available at: http://www.iea.org/publications/scenariosandprojections/ [Accessed 5 Jun. 2017].

IKEA. (2017). *IKEA / IKEA food services.* [online] Available at: http://www.ikea.com/ms/en_US/jobs/business_types/stores_retail/food_service.html [Accessed 5 Jun. 2017].

Inter IKEA. (2017a). *Our Business in brief - Inter IKEA Group.* [online] Available at: http://www.inter.ikea.com/en/about-us/business-in-brief/ [Accessed 5 Jun. 2017].

Inter IKEA. (2017b). *IKEA Industry - Inter IKEA Group.* [online] Available at: http://www.inter.ikea.com/inter-ikea-group/ikea-industry/ [Accessed 5 Jun. 2017].

Inter IKEA. (2017c). *IKEA Range & Supply - Inter IKEA Group.* [online] Available at: http://www.inter.ikea.com/inter-ikea-group/ikea-range-and-supply/ [Accessed 5 Jun. 2017].

PwC. (2017). *The Long View: How will the global economic order change by 2050?.* [online] Available at: http://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf [Accessed 3 Jun. 2017].

Other Articles and Reports

CDP. (2015). *Mind the Science Report.* [online] Available at: http://caringforclimate.org/wp-content/uploads/Mind-the-Science-Report.pdf [Accessed 5 Jun. 2017].

GHG Protocol. (2011). Corporate value chain (Scope 3) accounting and reporting standard. World Resources Institute and World Business Council for Sustainable Development, Washington, DC.

GHG Protocol. (2013). Technical guidance for calculating scope 3 emissions: Supplement to the corporate value chain (scope 3) accounting and reporting standard. World Resources Institute and World Business Council for Sustainable Development, Washington, DC.

IKEA. (2016). *Sustainability Report FY16.* [online] Available at: http://www.ikea.com/ms/en_US/img/ad_content/IKEA_Group_Sustainability_Report_FY16.pdf [Accessed 5 Jun. 2017].

IPCC (2014). Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

SBTi. (2015). *Science-based Target Setting Manual.* [online] Available at: http://sciencebasedtargets.org/wp-content/uploads/2015/09/SBTManual_PubComDraft_22Sep15.pdf [Accessed 5 Jun. 2017].

Appendix A Emission Driver Input

A.1 Raw Material

Table A.1. Collected drivers for raw material. Primary source: Sustainability Manager – Category Area (IKEA of Sweden).

Driver	How	Measurable	Examples
Renewable materials	Using non-fossil based materials	Yes	Exchanging fossil plastic to renewable plastics. Measurable by emission factors.
Recycled materials (metals)	Shorter upstream chain with less emissions	Yes	Recycled aluminium vs. virgin. Measurable by emission factors.
Recycled materials (fossil based)	Shorter upstream chain with less emissions	Yes	Recycled PET vs. virgin. Measurable by emission factors.
Recycled materials (renewable)	Shorter upstream chain with less emissions and prolonging bonded carbon.	Yes and No	Yes: Emission factors will show the impact of the shorter upstream chain. No: carbon bonding is not allowed to be considered.
Materials with low energy consuming processes	If different materials can be used for the same purpose in the product, the material with the lowest emissions should be chosen.	Yes and No	Yes: LVL (a layer glued beam) can exchange solid wood for furniture frames. No: Could be hard to estimate potential replacements.
Lightweight materials	Using less materials with same function in product.	Yes	Lowering material consumption. E.g. composite material (PP/renewable fibers) for seating shell solution will use less material than standard construction.
Materials with lower emissions due to sourcing	Same material but from different sources with lower emission	Yes	Solid wood from areas with full replantation.
Materials providing longer expected life length	Using materials that enables second life, second hand or replaceable parts will lower the emission by lowering the need of new products.	No (Yes)	Metal frame for sofas with exchangeable comfort parts instead of wooden frame with integrated comfort.

Driver	How	Measurable	Examples
Material sourcing closer to end user (shorter transport of recycled materials)	If sourcing materials closer to production unit/customer will lower transport emissions.	Yes	If increasing the use of recycled materials, the production units should be placed closer to the end user (as this is location of waste generation).
Resource Efficiency	Increasing yield in production will decrease total quantity used material for products.	No (Yes)	See left-left
Circular Economy	By reacquiring sold products from customer at their end of life, IKEAs need for virgin raw material will decrease.	No	See left-left

A.2 Food Ingredients

Table A.2. Collected drivers for food ingredient. Primary source: Project Engineer & Sustainability Developer (IKEA Food Services).

Driver	How	Measurable	Examples
Substitution of Item/ Ingredient	By substituting an item or ingredient with a lower impact alternative, the GHG emissions may be reduced.	Yes	*Example of ingredient substitution:* Substitute between items/ ingredients that can serve same function on plate but have different emission factors. *Example of item substitution:* National breakfast offer: Substitute butter offered on the menu with margarine (has 1/10th impact of butter).
Source substitution	Source an ingredient from a different region (country, continent), that might lead to benefits including less deforestation risks, and higher farm productivities.	No	*Example 1:* Source plant foods, e.g. potatoes, from countries with higher farm yields. *Limitations:* No country based emission factors yet.

Driver	How	Measurable	Examples
Targeted sales	Increase future sales of products that have low carbon footprint relative to products with high carbon footprint. Mainly driven through transparent customer communication and new range development.	Yes	Increase share of sales coming from plant based (veggie balls versus meatballs), seafood and lean meat foods (pork and chicken).
Range re-engineering	Develop new, healthier product offers on the range. Phase out some current products.	Yes	*Example 1:* Develop low-carbon dishes and increase sales of these whilst carbon intense dishes decrease. (Plant based and lean meat foods). *Example 2:* Reduce limit on the number of meatballs allowed on a plate. *Example 3:* Source low-carbon seafood instead of farmed salmon. *Example 4:* Develop a veggie hot-dog and set sales target so regular hot dogs sales decreases. Find alternative to dairy
Resource efficiency	Decrease the quantity of ingredients/items required to fulfil a particular function. IKEA Group has data on food waste in stores (aim is to have zero avoidable food waste). Though out of scope, the impact of their actions to decrease food waste would be in our scope.	Yes	Reducing avoidable food waste in the stores would mean less food ingredients are purchased to feed same number of people. Introduce more offers for children on our range. This can contribute to less food waste in the store.

A.3 Production

Table A.3. Collected drivers for production. Primary source: Sustainability Manager (IKEA Industry).

Driver	How	Measurable	Examples
Energy efficiency	Reduce by %: By making our internal and external production more energy efficient our Scope 3 emissions will decrease.	Yes	New technology increases the energy efficiency for all suppliers of textile products by 10%.
Energy Awareness program	Reduce by %: By making co-workers (operators, managers, ...) aware of energy consumption and possibility to affect by different ways of working.	Yes	Implement an Energy Awareness program for all suppliers.
Suppliers using bought green energy (electricity, heat, ..)	By influencing/changing suppliers' choice of electric source the impact of our products will be reduced.	Yes	*Example 1:* Sweden goes 100% renewable by 2040. *Example 2:* Supplier XX switches to an electric source, increasing the percentage of renewable share by xx%.
Self-provided energy (electricity, heat, ..)	If suppliers start to generate their own electricity, emissions from bought electricity will go down.	Yes	Electricity: Photovoltaics (PV) panels.
Change energy source: Production & Building, Internal Transport	This can be influenced by e.g. making our suppliers aware of their impact and choices by communication.	Yes	By influencing/changing suppliers' energy sources, e.g. changing from natural gas to biogas.
GHG free cooling solutions	By influencing/changing suppliers' choice of refrigerants, emission can decrease.	Yes	Using refrigerants with GWP=0 as cooling agent instead of HFC (~140 – 11 700 kg CO_2 eq).
Reduce leakage of refrigerant	Influence by providing information and communication of the issue as well as solutions.	Yes	Leakage checks and development plans.
Waste handling solutions	Firstly, decrease the waste from production. Secondly, utilise the waste in a sustainable/efficient way.	Yes	By influencing/changing suppliers waste handling solutions. i.e. avoiding landfill.

Driver	How	Measurable	Examples
Increase line utilisation	By better planning, maintenance, simulation of different production set-up.	Yes	Reduce idling time for machines. Use full capacity of machine line.

A.4 Product Use

Table A.4. Collected drivers for product use. Primary source: Project Leader (IKEA of Sweden).

Driver	How	Measurable	Examples
Energy efficiency of product	Reduce: By making our products more energy efficient, the overall energy consumption and therefore the footprint will be reduced.	Yes	Lighting: Improve efficacy of lamps/bulbs (lumen per W), i.e. light output per W.
Customer behaviour	By influencing/changing the customer behaviour the impact of our products will be reduced.	No	Lighting: By switching off lights, Appliances: Cooking in a more efficient way, e.g. “full throttle” on stove power and use a lid on the pot.
Energy generation at home	By enabling the customers to generate energy (electricity and/or heat) from a renewable source, less energy needs to be bought from the grid, which in pretty much all cases have a footprint	No	Electricity: Photovoltaics (PV) panels.
Customers using bought green electricity	By buying electricity with a higher renewable share, the footprint of our products will decrease.	No	This can be influenced by e.g. making our customers aware of their impact and choices by communication. Potentially also that IKEA sells renewable electricity to customers.
GHG free cooling solutions	By proving cooling solutions without any GHG, the footprint from refrigerators and freezers will decrease	Yes	Using refrigerants with GWP=0 as cooling agent instead of a HFC.
Renewable candles and other sold “fuels”	By making our candles and other sold “fuels” renewable, the net CO_2 emission will be zero.	Yes	See left-left.

Appendix B Simulation Tool Calculations

B.1 General

This section gives an introduction to the calculation methodology that is implemented in the simulation tool. An overview of the calculation principals is initially presented here and later referred to for the specific steering parameters.

B.1.1. Linear Interpolation

Many of the steering parameters are based on linear interpolation to calculate the rate of change of a variable for a specific year during the policy. Therefore, is a simple example presented here to demonstrate the concept:

$$RoC(t) = RoC(Start\ Year) + \big(RoC(End\ Year) - RoC(Start\ Year)\big) * \frac{t - Start\ Year}{End\ Year - Start\ Year}$$

where,

t = time, referring to a specific year.
RoC = Rate of Change for the variable that is altered in the policy.
Start Year = the year the policy is planned to start.
End Year = the year the policy is planned to be completely fulfilled.

A graphical representation of the principal is given in Figure B.1.

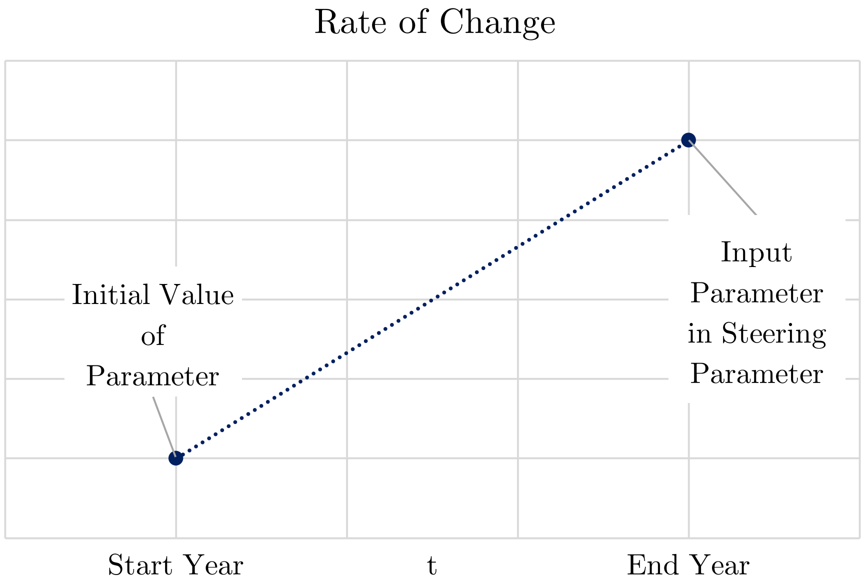


Figure B.1. Principal representation of linear interpolation of variables in steering parameters.

B.1.2 Business as Usual (BAU)

Raw Material, Food Ingredients and Product Use (Combustion of Fuels)

The BAU scenario for quantity used in raw material, food ingredient and products with fuel combustion is calculated as:

$$Quantity(t) = Quantity(t-1) * Growth\ Factor$$

where,

Quantity = the quantity used for the specific year.
Growth Factor = the growth factor for the specific emission area and/or product.

The emissions are calculated as:

$$GHG\ Emissions(t) = Quantity(t) * EF$$

where,

GHG Emissions = the GHG emissions for the specific year.
EF = the emission factor (kg CO_2 eq/kg) for a specific raw material (extraction and transformation factors combined), food ingredients or combustion fuel.

Production

The BAU scenario for the energy consumption in production is calculated as:

$$Energy\ Consumption(t) = Energy\ Consupmtion(t-1) * Growth\ Factor$$

where,

Energy Consumption = the energy consumption used for the specific year.

For emissions relating the combustion of fuels (Production & Building and Internal Transport) are calculated as:

$$GHG\ Emissions(t) = Energy\ Consupmtion(t) * EF$$

where,

EF = the emission factor (kg CO_2 eq/kWh) for a specific fuel, as defined in Section 4.2.3 Production Footprint.

For electricity related emission areas, consideration is taken to the projected increase of renewable share in the electricity grid. The increase is based on the energy projection published by the European Commission:

European Commission. (2017). Energy modelling - interactive graphs - Energy - European Commission. [online] Available at: https://ec.europa.eu/energy/en/content/energy-modelling-interactive-graphs?type=msline&themes=s_69_-of-carbon-free-res-nuclear-gross-electricity-generation [Accessed 5 Jun. 2017].

The increase in the renewable share in the electricity grid is as:

$$Yealy\ Increase = \left(\frac{Renewable\ Share_{Start\ Year}}{Renewable\ Share_{End\ Year}}\right)^{\frac{1}{End\ Year - Start\ Year}} - 1 = 0{,}79\%$$

where,

Start Year = 2015
End Year = 2050
Renewable Share$_{\text{Start Year}}$ = 55,48% (European Commission, 2017)
Renewable Share$_{\text{End Year}}$ = 73,13% (European Commission, 2017)

Note! It is assumed that this increase applies for all suppliers, independent if they are located in the other countries outside of the EU.

The emissions are then calculated as:

$$GHG\ Emissions(t) = Energy\ Consupmtion(t) * EF$$

where,

EF = the emission intensity factor kg (CO_2 eq/kWh) based on the energy mix and renewable in the electricity grid (based in supplier specific measure or else the country average, as defined in Section 4.2.3 Production Footprint).

Note! The CO_2 footprint/kWh is calculated using the assumption that 100% renewable share gives an energy intensity of zero CO_2 footprint/kWh.

Refrigerants

The BAU scenario for the refrigerant consumption is calculated as:

$$Refrigerant\ Consumption(t) = Refrigerant\ Consumption(t-1) * Growth\ Factor$$

where,

Refrigerant Consumption = the refrigerant consumption for the specific year.

The emissions are calculated as:

$$GHG\ Emissions(t) = Refrigerant\ Consumption(t) * EF$$

where,

EF = the emission factor (kg CO_2 eq/kg) for a specific refrigerant, as defined in Section 4.2.3 Production Footprint.

Product Use – Electricity Consuming Products

In similarity to the BAU for the renewable share of electricity in production, the same principal is applied for the product use. The energy consumption is calculated depending on the product area and classification, as defined in Section 4.2.4 Product Use Footprint, and calculated as:

$$Energy\ Consumption(t) = Energy\ Consupmtion(t-1) * Growth\ Factor$$

where,

Energy Consumption = the energy consumption used for a specific product for the specific year.

The emissions are then calculated as:

$$GHG\ Emissions(t) = Energy\ Consupmtion(t) * EF$$

EF = the emission intensity factor kg (CO_2 eq/kWh) based on the energy mix and renewable in the electricity grid in the country the product is sold.

B.1.3 Substitution/Relative Share

Several steering parameters address substitution between High and Low Value Alternatives. This section presents the principal of the calculation methodology for such steering. Firstly, linear interpolation is used for the input parameter that the substitution is defined in (e.g. "New Share" presented in Section 6.1.1.1 Substitute Material and Section 6.1.2.3 Substitute Item). To calculate the share of quantity change for a specific year during the policy, the variable of substitution is calculated as:

$$Variable\ Change(t) = Variable(t-1)_{BAU} * (1 - Substitution\ Parameter(t))$$

where,

Variable Change = the change of the variable that is substituted, e.g. quantity or energy consumption.
$Variable_{BAU}$ = the BAU level of the variable that is substituted.
Substitution Parameter = the input parameter that the substitution is defined in, e.g. "New Share"

The variable that is substituted from is then calculated as:

$$Variable(t) = (Variable(t-1) - Variable\ Change(t)) * Growth\ Factor$$

and the variable that is substituted to as:

$$Variable(t) = (Variable(t-1) + Variable\ Change(t)) * Growth\ Factor$$

For the steering parameter presented in Section 6.1.1.1 Substitute Material, the weight ratio of the material is also considered and calculated as:

$$Variable(t) = \left(Variable(t-1) + \frac{Variable\ Change(t)}{Weight\ Ratio}\right) * Growth\ Factor$$

B.2 Raw Material

B.2.1 Substitute Material

This steering parameter uses Substitution/Relative Share as defined above. “Variable” refers to the material quantity and “Substitution Parameter” is the input parameter “New Share (%)”.

B.2.2 Lightweight Solution

Linear interpolation is used on the input parameter “Percentage of Change (%)”. The material quantity is then calculated as:

$$Quantity(t) = Quantity(t-1) * (Growth\ Factor - Percentage\ of\ Change(t))$$

B.2.3 Altering CO$_2$ Emission Factor

Linear interpolation is used on the input parameter “Percentage of Change (%)”. The emission factor is then calculated as:

$$Emission\ Factor(t) = Emission\ Factor(t-1) * (1 + Percentage\ of\ Change(t))$$

B.3 Food Ingredient

B.3.1 Relative Share of Item in a Product

This steering parameter uses Substitution/Relative Share as defined above. “Variable” refers to the quantity of the ingredients in the product and “Substitution Parameter” is the input parameter “New Relative Share of Product (%)”.

B.3.2 Range Re-engineering

This steering parameter uses no calculations.

B.3.3 Substitute Item

This steering parameter uses Substitution/Relative Share as defined above. “Variable” refers to the quantity of the ingredients in the item and “Substitution Parameter” is the input parameter “New Share (%)”.

B.3.4 Substitute Ingredient Class

This steering parameter uses Substitution/Relative Share as defined above. “Variable” refers to the quantity of the ingredients in the ingredient class and “Substitution Parameter” is the input parameter “New Share (%)”.

B.3.5 Targeted Sales

Linear interpolation is used on the input parameter “Change in Sales (%)”. The quantity of the ingredients in the product is then calculated as:

$$Quantity(t) = Quantity(t-1) * (Growth\ Factor + Change\ in\ Sales(t))$$

B.3.6 Altering CO_2 Emission Factor

Linear interpolation is used on the input parameter “Percentage of Change (%)”. The emission factor is then calculated as:

$$Emission\ Factor(t) = Emission\ Factor(t-1) * (1 + Percentage\ of\ Change(t))$$

B.4 Production

B.4.1 Energy Efficiency

Linear interpolation is used on the input parameter “Energy Efficiency (%)”. The energy consumption is then calculated as:

$$Energy\ Consumption(t) = Energy\ Consumption(t-1) * (1 - Energy\ Efficiency(t))$$

B.4.2 Substitute Energy Fuel Source

This steering parameter uses Substitution/Relative Share as defined above. “Variable” refers to the energy consumption and “Substitution Parameter” is the input parameter “New Share (%)”.

B.4.3 Renewable Share of Electricity

Linear interpolation is used on the input parameter “New Renewable Share (%)”. The emission factor is then calculated using the assumption that 100% renewable share implies an emission factor of 0 kg CO_2 eq/kWh. The emission factor is then calculated using linear interpolation. To illustrate the concept, Figure B.2 shows an example with three suppliers with different initial renewable shares (and thereby emission factors). These are represented as the small dots in the graph. Ponder that the renewable share during a policy is calculated as 50%. The new emission factor during that specific year in the policy is highlighted as the bigger dots in the graph.

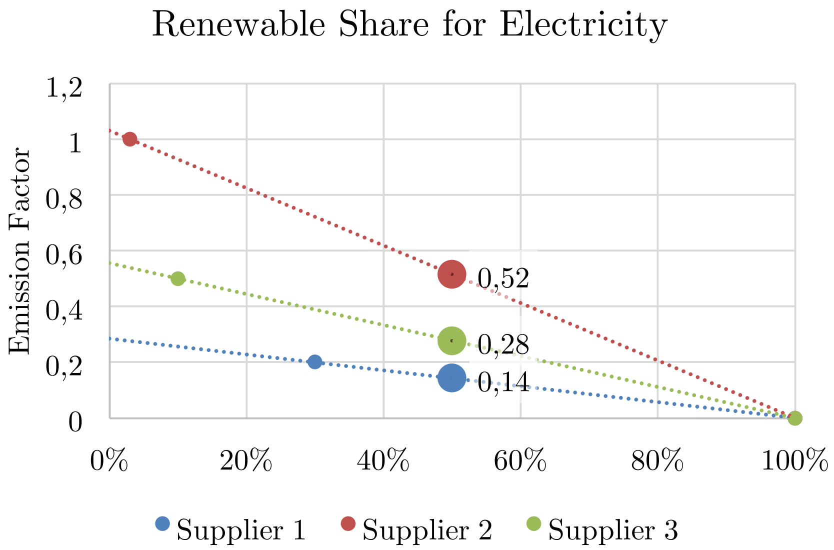


Figure B.2. The concept of calculating the emission factor as a function of the renewable share.

B.4.4 Refrigerant Spillage Reduction

Linear interpolation is used on the input parameter "Reduction (%)". The energy consumption is then calculated as:

$$Refrigerant\ Consumption(t) = Refrigerant\ Consumption(t-1) * (1 - Reduction(t))$$

B.4.5 Substitute Refrigerants

This steering parameter uses Substitution/Relative Share as defined above. "Variable" refers to the refrigerant consumption and "Substitution Parameter" is the input parameter "New Share (%)".

B.5 Product Use

B.5.1 Energy Efficiency

Linear interpolation is used on the input parameter "Energy Efficiency (%)". The energy consumption is then calculated as:

$$Energy\ Consumption(t) = Energy\ Consumption(t-1) * (1 - Energy\ Efficiency(t))$$

B.5.2 Substitute Product Types

This steering parameter uses Substitution/Relative Share as defined above. “Variable” refers to the quantity of sold product types and “Substitution Parameter” is the input parameter “New Share (%)”.

B.5.3 Renewable Share of Combustion Fuel

This steering parameter uses the same concept for calculation of the emission factor as the one represented in Figure B.2.

Appendix C Input Examples for Steering Parameters

The input parameters for the examples presented in Section 6.1 Steering Parameters are presented in this section.

C.1 Raw Material

C.1.1 Substitute Material

Table C.1. Input for the example presented in Section 6.1.1.1 Substitute Material.

Parameter		Input
Material	**From**	Metal A
	To	Metal A
Material Form	**From**	Machined Part
	To	Machined Part
Recycled/Virgin*	**From**	Virgin
	To	Recycled
Renewable/Fossil Based*	**From**	
	To	
Weight Ratio		1:1
Start Year		2020
End Year		2030
New Share (%)	**From**	20%
	To	100%

C.1.2 Lightweight Solution

Table C.2. Input for the example presented in Section 6.1.1.2 Lightweight Solution.

Parameter	Input 1	Input 2
Material	Metal A	Metal A
Material Form	Machined Part	Machined Part
Recycled/Virgin*	Virgin	Recycled
Renewable/Fossil Based*		
Start Year	2020	2020
End Year	2030	2030
Percentage of Change (%)	20%	20%

C.1.3 Altering CO_2 Emission Factor

Table C.3. Input for the example presented in Section 6.1.1.3 Altering CO2 Emission Factor.

Parameter	Input 1	Input 2
Material	Material A	Material A
Material Form	Machined Parts	Machined Parts
Recycled/Virgin*	Virgin	Recycled
Renewable/Fossil Based*		
Emission Factor Type	Material Transformation	Material Transformation
Start Year	2020	2020
End Year	2035	2035
Percentage of Change (%)	-25%	-25%

C.2 Food Ingredient

C.2.1 Relative Share of Item in a Product

Table C.4. Input for the example presented in Section 6.1.2.1 Relative Share of Item in a Product.

Parameter		Input
Product		Product A
Item	**From**	Meat Item
	To	Vegetable Item
Start Year		2020
End Year		2020
New Relative Share of Item (%)		10%

C.2.2 Range Re-engineering

Table C.5. Input for the example presented in Section 6.1.2.2 Range Re-engineering.

Parameter		Input
Product Name		“Vegetable Hot Dog”
Item	**1**	Vegetable Sausage
	2	Hot Dog Roll

C.2.3 Substitute Item

Table C.6. Input for the example presented in Section 6.1.2.3 Substitute Item.

Parameter		**Input 1**	**Input 2**
Product	**From**	Hot Dog	Hot Dog
	To	Vegetable Hot Dog	Vegetable Hot Dog
Item	**From**	Meat Sausage	Vegetable Sausage
	To	Hot Dog Roll	Hot Dog Roll
Start Year		2020	2035
End Year		2020	2035
New Share (%)		20%	20%

C.2.4 Substitute Ingredient Class

Table C.7. Input for the example presented in Section 6.1.2.4 Substitute Ingredient Class.

Parameter		**Input**
Ingredient Class	**From**	Meat Class A
	To	Meat Class B
Start Year		2020
End Year		2050
New Share (%)		20%

C.2.5 Targeted Sales

Table C.8. Input for the example presented in Section 6.1.2.5 Targeted Sales.

Parameter	**Input 1**	**Input 2**
Product	Product A	Product B
Start Year	2030	2030
End Year	2040	2040
Change in Sales (%)	15%	-10%

C.2.6 Altering CO_2 Emission Factor

Table C.9. Input for the example presented in Section 6.1.2.6 Altering CO2 Emission Factor.

Parameter	Input
Ingredient	Ingredient A
Start Year	2020
End Year	2050
Percentage of Change (%)	-25%

C.3 Production

C.3.1 Energy Efficiency

Table C.10. Input for the example presented in Section 6.1.3.1 Energy Efficiency.

Parameter	Input
Unit	Unit A
Category Area	All Category Areas
Main Category	All Main Categories
Segment	All Segments
Continent	Asia
Country	All countries
Exception(s)	Category Area A
Energy Source	Production & Building (Fuels)
Start Year	2020
End Year	2050
Energy Efficiency (%)	40%

C.3.2 Substitute Energy Fuel Source

Table C.11. Input for the example presented in Section 6.1.3.2 Substitute Energy Fuel Source.

Parameter		Input
Unit		All Units
Category Area		All Category Areas
Main Category		All Main Categories
Segment		All Segments
Continent		All continents
Country		All countries
Exception(s)		None
Energy Source		All Energy Sources
Energy Fuel Source	From	Natural Gas
	To	Biogas

Parameter	Input
Start Year	2025
End Year	2050
New Share (%)	0%

C.3.3 Renewable Share of Electricity

Table C.12. Input for the example presented in Section 6.1.3.3 Renewable Share of Electricity.

Parameter	Input
Unit	All Units
Category Area	All Category Areas
Main Category	All Main Categories
Segment	All Segments
Continent	All continents
Country	Sweden
Exception(s)	None
Start Year	2020
End Year	2040
New Renewable Share (%)	100%

C.3.4 Refrigerant Spillage Reduction

Table C.13. Input for the example presented in Section 6.1.3.4 Refrigerant Spillage Reduction.

Parameter	Input
Unit	All Units
Category Area	All Category Areas
Main Category	All Main Categories
Segment	All Segments
Continent	All continents
Country	All countries
Exception(s)	None
Start Year	2020
End Year	2030
Reduction (%)	60%

C.3.5 Substitute Refrigerants

Table C.14. Input for the example presented in Section 6.1.3.5 Substitute Refrigerants.

Parameter		**Input 1**	**Input 2**	**Input 3**
Unit		All Units	All Units	All Units
Category Area		All Category Areas	All Category Areas	All Category Areas
Main Category		All Main Categories	All Main Categories	All Main Categories
Segment		All Segments	All Segments	All Segments
Continent		All continents	All continents	All continents
Country		All countries	All countries	All countries
Exception(s)		None	None	None
Refrigerant	**From**	Refrigerant A	Refrigerant B	Refrigerant C
	To	Refrigerant D	Refrigerant D	Refrigerant D
Start Year		2020	2020	2020
End Year		2040	2040	2040
New Share (%)		0%	0%	0%

C.4 Product Use

C.4.1 Energy Efficiency

Table C.15. Input for the example presented in Section 6.1.4.1 Energy Efficiency.

Parameter	**Input 3**	**Input 1**	**Input 2**
Home Furnishing Business	All Home Furnishing Business	All Home Furnishing Business	All Home Furnishing Business
Product Area	Product Area A	Product Area B	Product Area B
Product Type	All Product Types	All Product Types	All Product Types
Continent	All continents	All continents	All continents
Country	All countries	All countries	All countries
Exception(s)	None	None	None
Start Year	2020	2020	2030
End Year	2040	2030	2040
Energy Efficiency (%)	30%	50%	20%

C.4.2 Substitute Product Types

Table C.16. Input for the example presented in Section 6.1.4.2 Substitute Product Types.

Parameter		Input 1	Input 2
Home Furnishing Business		All Home Furnishing Business	All Home Furnishing Business
Product Area		All Product Areas	All Product Areas
Product Type	**From**	Product Type A	Product Type A
	To	Product Type B	Product Type C
Continent		All continents	All continents
Country		All countries	All countries
Exception(s)		None	None
Start Year		2025	2025
End Year		2025	2035
New Share (%)		20%	80%

C.4.3 Renewable Share of Combustion Fuel

Table C.17. Input for the example presented in Section 6.1.4.3 Renewable Share of Combustion Fuel.

Parameter	Input 1	Input 2
Home Furnishing Business	All Home Furnishing Business	All Home Furnishing Business
Product Area	Candles	Candles
Product Type	All Product Types	All Product Types
Continent	All Continents	All Continents
Country	All Countries	All Countries
Exception(s)	None	None
Start Year	2020	2030
End Year	2030	2050
New Renewable Share (%)	75%	100%