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Identifying Risks in the Supply Chain of Materials at Volvo Cars

A Concept Modelling of Environmental, Social, and Technical Risks

Master’s thesis in Industrial Ecology

Simon Aglund
Julia Benson

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS

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Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

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ABSTRACT

A few commercial companies in different industries have developed tools for identifying and assessing both environmental and social material impacts throughout the supply chain. Facing the contemporary climate and environmental crisis, companies need to advance their sustainable development and acknowledge sustainability risks. Volvo Cars is a global Swedish premium car company that wants to develop their own tool for managing sustainability risks. To achieve their sustainability goals, the risks related to the materials used in their products need to be understood. Therefore, this thesis was conducted on behalf of Volvo Cars to lay the foundation for a conceptual model for identification of environmental, social, and technical risks. The model aims to function as a guide in research & development and procurement of materials.

Collective understanding of terminology is crucial for a model's utility. Through literature research, interviews and workshops, the terminology used in this conceptual model was polished while compiling issues important to both external and internal stakeholders. The model is based on *A Relational Theory of Risk* by Boholm & Corvellec (2011), which defines risk as a combination of three elements i.e., object at risk, risk object, and the relationship of risk connecting the two. By first determining what is important to protect, cause-effect chains can be mapped, identifying the threatening objects that could potentially cause harm. The final model includes 15 objects at risk divided into three systems: the *Nature system*, the *Social system*, and the *Technical system*. Additionally, the model includes suggested indicators each object at risk to enable quantification and comparison between different material options.

It has become clear that having a shared understanding of the meaning of different concepts is crucial for developing a model like this. It is therefore important to have a clearly defined terminology before introducing any kind of management tool, especially regarding sustainability risks. The model is not operational at its current state, and the next step for Volvo Cars would be to investigate in further developments such as finding suitable datasets and introducing a weighting system. This would help with prioritisation, highlighting the most critical issues.

Keywords: risk, conceptual model, terminology, Volvo Cars, supply chain, sustainability

Glossary

ADI – Acceptable Daily Intake
AP – Acidification Potential
CRM – Critical Raw Materials (according to EU's definitions)
DALY – Disability adjusted life years
EP – Eutrophication Potential
EP&L – The Environmental Profit & Loss
EPA – Environmental Protection Agency
ESG – Environmental, Social, and Governance
EV – Electric Vehicle
FAETP – Freshwater Aquatic Ecotoxicity Potential
FPIC – Free, prior and informed consent
GM – General Motors
GWP – Global Warming Potential
HDI – Human Development Index
HIIK – Heidelberg Institute for International Conflict
HTP – Human Toxicity Potential
ISO - International Organisation for Standardisation
IUCN – International Union for Conservation of Nature
LCA – Life Cycle Analysis
MAETP – Marine Aquatic Ecotoxicity Potential
N – Nitrogen
NGO – Non-Governmental Organisation
N-MSI – Nike Materials Sustainability Index
Object at risk – An object with assigned value, potentially exposed to something that could cause harm
ODP – Ozone Depletion Potential
P – Phosphorus
PDI – Predicted Daily Intake
PEC – Predicted Environmental Concentration
PNEC – Predicted No-Effect Concentration
POCP – Photo-Oxidant Creation Potential
R&D – Research and development
RA – Risk assessment
Relationship of risk/Risk relation – A relationship connecting an object posing as a threat with an object worth protecting. The relationship of risk can consist of several links.
Risk category – An umbrella including the three terms: "Risk object", "Relationship of risk" and "Object at risk".
Risk object – An object/event posing a threat to an object with assigned value (object at risk)
RLI – Red List Index
RMO – Raw Material Outlook
Sb – Antimony
SDG – Sustainable Development Goals
SHBD – Social Hotspots Database
S-LCA – Social Life Cycle Analysis
TETP – Terrestrial Ecotoxicity Potential
UCLA – University of California, Los Angeles
UN – United Nations

UNGC – UN Global Compact
WEEE – Waste Electrical and Electronic Equipment
WGI – Worldwide Governance Indicator
WWF – World Wildlife Fund
YLD – Years Lost due to Disability
YLL – Years of Life Lost
Yrs – Years

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1. Introduction

The automotive industry is one of the most important industries for EU's welfare, having a turnover representing over 7% of the GDP (European Commission, n.d.). For the last fifty years the use of private cars has increased and become a central part in peoples' everyday life (Jasinski et al., 2015). Consequently, the expansion of the automotive industry has resulted in various sustainability issues, both environmental and social, related to the industry's supply chain (Jasinski et al., 2015). This has brought stricter regulations and legislations from policymakers and other stakeholders, forcing the companies in the automotive industry to examine potential negative environmental and social impacts from their operations (Jasinski et al., 2015).

Volvo Cars is a global Swedish premium car company, operating in the automotive industry, and this thesis was conducted on their behalf. The company aims to provide sustainable and safe transportation possibilities, and wants to lead the automotive industry change towards, amongst others, electrification, and safety (Volvo Car Corporation, 2020). By 2040, Volvo Cars is determined to be a climate neutral and circular business (Volvo Car Corporation, 2022). Furthermore, the company wants to become a recognised leader in ethical and responsible business (Volvo Car Corporation, 2022). Together *Climate Action, Circular Economy*, and *Ethical and Responsible Business* form Volvo Cars' three sustainability pillars (Volvo Cars Corporation, 2021-a). According to Volvo Cars' (2021-a) strategy, the aim of having those three pillars is to create a more attractive and profitable business while both protecting the planet and engage in the wellbeing of employees, consumers, and other actors within the supply chain.

Facing a climate and environmental crisis, companies need to assess potential sustainability risks, fostering the company's sustainable development (Schulte & Hallstedt, 2018). A relationship between the company's objectives, stakeholder value, and issues related to sustainability needs to be established. For Volvo Cars to achieve their sustainability goals, the company needs to understand what social and environmental risks are connected to their choices of materials and components, since these stem from numerous suppliers. These risks need to be considered since managing sustainability issues in the supply chain contributes to a company's sustainable development (Salvado et al., 2015). To facilitate the management of sustainability risks, risk assessment tools should be introduced to all decision-making processes throughout the organisation (Schulte & Hallstedt, 2018). Implementing a tool for sustainability risk assessment in an early stage of research and development (R&D) could guide the choice of materials and suppliers.

However, there are certain challenges with implementing assessments of sustainability risks, since modern business supply chains consist of complex linkages between sometimes as much as thousand suppliers distributed across a number of tiers, a structure that organises suppliers according to their distance to the final product (Drive Sustainability et al., 2018). Only the suppliers on the first tier directly conduct business with the vehicle company, while there are a range of smaller suppliers scattered on sub-tiers that can be harder to monitor (Legget, 2022). Therefore, decision making about risk mitigation is difficult, since it is hard to provide a holistic picture of potential sustainability risks in globalised supply chains (Xu, et al., 2019). Businesses are sourcing their materials and components from numerous countries, complicating the due diligence of suppliers, where the standard of the supplier is investigated (Drive Sustainability et al., 2018).

Some other general challenges of applying sustainability risk management in companies today, besides the complexity of supply chains, are that existing tools are not comprehensible enough, the guidelines are not clearly defined, time-consuming processes, and that documentation is lacking (Schulte & Hallstedt, 2018). This needs to be considered when developing and applying a methodology for Volvo Cars.

2. Background

The complexity of today's supply chains has created a need for easily accessible information about environmental, social, and governance (ESG) risks, and to develop methodologies for identifying, assessing, and mitigating the potential occurrence of such (Drive Sustainability et al., 2018). ESG criteria are a guide for responsible investing, and to make informed decisions about investments, stakeholders are increasingly requesting assessments of ESG risks (Det Norske Veritas, 2022). Such risks include for example climate change, human rights abuses, working and safety conditions, and compliance to laws and regulations (Det Norske Veritas, 2022). However, there is limited access to accurate and current data, a big obstacle when aiming for implementation of similar strategies (Drive Sustainability et al., 2018). A few other companies, mainly not in the automotive industry, have presented tools for assessing these issues, where the limitation of retrieving data is acknowledged. These tools have in this thesis been used as a source of inspiration when developing a conceptual model for Volvo Cars. But before these tools can be analysed, it is important to understand why a conceptual model and a shared terminology is needed when communicating risks within companies.

2.1. Conceptual Model

Communicating risks between different teams and departments requires a clear terminology regarding what is meant by risk perception, ranking of risks, and their magnitude. Employees and other stakeholders with various backgrounds and knowledge levels are likely to apply different terminology for similar concepts (Carlson et al., 2004). Therefore, the company needs a structured method to assess identified risks, and the ability to communicate clear and consistent recommendations. A conceptual model, a compilation of defined concepts and how they relate, could enable visualisation of business-related risks that might not be initially apparent (Carlson et al., 2004; Schulte et al., 2020). According to Tivander et al. (2010), a conceptual model provides a framework in which a quantitative model can be constructed. The concepts represent what will later be the defined dimensions and, subsequently, something quantifiable through the addition of data. It is also partly designed for the purpose of including factors which LCA omits, such as less quantifiable flows (Tivander et al., 2010).

By developing a conceptual model that can be applied to different kinds of risks, Volvo Cars' internal and external communication can be facilitated between the parties involved. However, when talking about risk, it needs to be agreed on what the term means in this context. Thus, to define risks individual and social practices have to be investigated as they emerge from a common understanding (Boholm & Corvellec, 2011). Without proper definitions, risk communication will be complicated, since it is dependent on collective definitions of what is deemed a risk. People need to categorise and classify "events, objects, and beings in time and in space" (Boholm & Corvellec, 2011). Together, categorisation and classification create a conceptual model, organising concepts based on their relations to each other (Boholm & Corvellec, 2011).

There are a few companies in different industries that have developed tools for assessing sustainability risks. Whether they have used a conceptual model to develop these methodologies is not stated. However, this thesis work has been somewhat inspired by these approaches, which are summarised below.

2.2. Materiality Assessment Tools at Additional Commercial Companies

Apple, Nike, Filippa K, General Motors (GM), and Stella McCartney are commercial companies in different industries, having developed various tools for assessing their material's environmental or social impacts which are described below. Looking at the five companies identified by the authors, it is clear that the fashion industry is in the forefront in this area.

Apple Inc. is an American computer, smartphone, and software manufacturer (Levy, 2022). They have developed a methodology for assessing general social and environmental risks related to their supply chains (Apple Inc., 2019). In the methodology, Apple (2019) evaluates environmental and social impacts from 45 mined elements used in many consumer electronic products, using indicators with regularly updated data from existing datasets in three focus areas. The first area – supply – concerns impacts related to the availability of materials, the second – environment – includes environmental impacts connected to the mining and extraction sector, and the third – society – includes human rights violations (Apple Inc., 2019). Adding the mass of material used in the products giving the materials different scores, Apple (2019) weighs the results and determines how to prioritise different materials, and what strategies should be applied. Two main limitations that Apple (2019) acknowledge regarding their tool, is that it can only be applied to mined materials, and that there is generally a big lack of data when assessing these kinds of impacts.

Nike, Inc. is an American sportswear company (Encyclodpaedia Britannica, 2019), and according to them (Nike, Inc., 2012), they are world leading in designing, marketing, and distributing sportswear. The company recognises that the materials used in their products are the major contributors to the environmental impact. To assess the impacts of these materials, Nike, Inc. has developed the Nike Materials Sustainability Index (N-MSI), which calculates relative scores for the cradle-to-gate impact of each material. The N-MSI is based on two principles when scoring: three categories of points and even weighting of four environmental impacts. One of the categories uses public information and information from suppliers to assess the four environmental impacts, arriving at a score for each raw material. To try to compensate for the shortcomings of public and supplier data, the category is then complemented with an indicator-based score (Nike, Inc., 2012). With the tool, Nike only focusses on environmental impacts, not including social impacts.

Filippa K is a Swedish clothing company, and its goal is to produce minimalist and long-lasting clothes (Filippa K, 2022-a). The company has developed a tool for assessing the entire lifecycle of a piece of clothing called Fibre Tool (Filippa K, n.d.). The tool scores each type of fibre based on its production impact and durability, and the score goes from class 1 to 4, where 1 and 2 are the ones regarded as the more sustainable options. According to Filippa K (n.d.) The Fibre Tool is mostly used in the design phase to aid in making sustainable choices.

General Motors (GM) is an American automotive company (General Motors, 2022). They are working on continuous development of an internal tool for assessment of material sustainability, which includes environmental product declarations (EDPs) and life cycle assessments (LCAs). These LCAs use supplier data from "cradle-to-gate", where "gate" is the delivery to GM. The gathered data contains information about renewable and recycled content, while also enabling the measurement of several environmental impacts. The tool helps them reach their goals both regarding sustainable materials and zero emissions (General Motors, 2021).

The British luxury fashion company Stella McCartney uses and continuously customises the Environmental Profit & Loss (EP&L) tool to measure environmental impacts and the societal impacts they can cause (Stella McCartney, 2020). The tool is applied on raw material extraction to product manufacturing, and measures how company activities impact the environment by using methods for accounting natural capital (Stella McCartney, 2020). The tool combines primary data from suppliers and secondary data from, for example, LCAs (Stella McCartney, 2020). The indicators are then compared to each other, highlighting hotspots in the supply chain and what materials have the highest impacts (Stella McCartney, 2020). Regarding social supply chain issues, Stella McCartney (2020) uses social compliance assessment. The company acknowledges that there is a trade-off between maintaining an established methodology and improving it with new, relevant data (Stella McCartney, 2020). In their Eco Impact Report, the company provides methodology changes as well as the data sources used (Stella McCartney, 2020).

All five tools provide several supply chain risks that can possibly be included in a model used by Volvo Cars. However, as stated in *2.1. Conceptual Model*, when developing a new model, it is necessary to establish a terminology that is shared within Volvo Cars, making it is suitable for the company to use.

2.3. Aim & Limitations

The aim of the thesis was to develop a new conceptual model for risk identification at Volvo Cars. The finished model identifies risks of both environmental, social, and technical natures and aids communication surrounding risks, and can be used to develop a useful tool at a later stage. It can then be used as a guide in, for example, R&D and procurement of materials and components.

The thesis does not quantify the identified risks due to time limitations. The model considers the materials and related processes through the entire value chain of the car but does not include the tailpipe emissions of the product nor emissions from making the fuel. Additionally, only internal stakeholders have been considered for stakeholder interactions.

To fulfil the aim, following research questions were answered:

- What could a conceptual model, suitable for identifying risks, look like?
- What terminology can be used to make the conceptual model comprehensible to all stakeholders?
- Which are the main supply chain risks?

3. Theory

As has already been mentioned, it is crucial to establish the concept of risk when creating a model for risk identification. Only then can different types of risk be identified and assessed.

3.1. Relational Theory of Risk

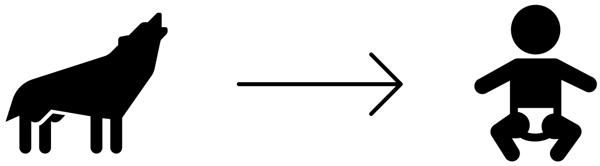
Several risk definitions exist, whereof most contain three common elements: risk object, a presumed harm, and a connection linking the harm to the object (Boholm & Corvellec, 2011). In Boholm and Corvellec's (2011) relational theory of risk, risk is understood to be the outcome of a linkage between the risk object and an object at risk, where the risk object poses a threat to the object at risk. Their schematic illustration (Boholm & Corvellec, 2011) of the relational theory of risk is as follows:

$$[Risk\ object] \leftarrow (Relationship\ of\ risk) \rightarrow [Object\ at\ risk]$$

The three elements do not exist separately, but are constructed simultaneously in a given situation. From a social perspective it can be hard to specify these three terms since individuals perceive risks and the objects related to them differently, as well as the value of various objects (Boholm & Corvellec, 2011). It is therefore important to investigate *how* people understand risks, rather than *what* they think risk is, which is dealt with in the relational theory. The differences found in risk perception are caused by differences in cultural values and beliefs, an important aspect to include when analysing and defining risk (Boholm & Corvellec, 2011). A company consisting of many different departments can therefore have more difficulties finding consensus surrounding risk-related definitions, especially between different work areas. According to Boholm and Corvellec (2011), this motivates the use of the label "risk object" instead of identifying the risk-causing object as "dangerous" or as a "hazard". Something deemed a risk object by one individual can be an object at risk in another person's mind, which will be further illustrated in Figure 1 and Figure 2. This implies a fluidity in the risk object's identity, emphasising the differences in what is considered dangerous or valued by different individuals, groups of people, or different parts of society (Boholm & Corvellec, 2011).

The object at risk has to have some kind of value that can be lost due to the risk, since the object at risk consists of attributes related to need for protection and care, i.e., something to safeguard (Boholm & Corvellec, 2011). Value can allude to a variety of elements that are considered worthy by the observer, such as natural values, principles, or existing conditions (Boholm & Corvellec, 2011). Even if value can be interpretated in several ways depending on the observer, the modern society more often describes value in monetary terms, which is often the case for a company. The third term in the relational theory, the relationship of risk, is a social construct that is shaped by an observer's cultural beliefs and values (Boholm & Corvellec, 2011). Depending on surrounding circumstances and the observing individual's previous experiences, what they deem dangerous or threatening will vary. However, the socially constructed relationship would likely not be irrational or disconnected from reality.

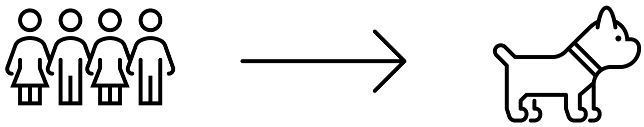
For clarification, this phenomenon is explained by Boholm and Corvellec (2011) with an example, which is illustrated in Figure 1 and Figure 2. In Figure 1, one perspective on the relationship of risk between a dog and a child is depicted. In an environment where dogs and children are co-existing, individuals who are afraid of dogs would be more likely to view a dog as a threat (risk object), exposing a child (object at risk) to potential harm (relationship of risk). The observer's perception of the situation could be that the relationship of risk between the two objects is a potential dog attack.



$$[Dog] \rightarrow (Dog\ attacking\ child) \rightarrow [Child]$$

Figure 1. Situation where the risk object is a dog, the object at risk is a child, and the relationship of risk is an attack.

From another point of view, another individual could make the opposite assessment of a similar situation involving the same objects, which is illustrated in Figure 2. They might have previous experiences with insensitive children (risk object) harassing dogs (object at risk). Therefore, this individual sees the relationship of risk as the children's harassment of the dog.



$$[Children] \rightarrow (Children\ harassing\ dog) \rightarrow [Dog]$$

Figure 2. Situation chain where the risk object is a group of children, the object at risk is a dog, and the relationship of risk is harassment.

The cause-effect chains with dogs and children are used to ease the understanding the concept of the relational risk theory. This framework can be applied to issues related to environmental, social, and technical supply chain risks. Categorising the risks into these three areas facilitates the structuring of the conceptual model and sorting the cause-effect chains.

3.2. The Three Systems to Describe the World

An example of a conceptual model is the SPINE model (Sustainable Product Information Network for the Environment), which is described in the ChEmiTecs report (Tivander et al., 2010), and which was created to structure and describe main aspects of information in LCA. It consists of three systems which are used to describe the world and life in it. The model divides the tangible part of the world into the *Technical* and *Nature system*, where the technical system includes artificial, human-made constructs for extraction and refinement of natural resources, and the nature system comprises the opposite, which is natural and unaltered by humans. To transform natural resources into useful goods, the technical system changes aspects of the nature system (Tivander et al., 2010). For example, a river is in the nature system, while the riverside farmland and the grazing animals on it belong to the technical system. Third is the *Social system*, which includes the intangible human constructs and a subjective assessment of the effects on the changes made in the nature system. If the social system deems the effects of the changes in the nature system as negative, they are referred to as environmental problems (Tivander et al., 2010). Examples of the social system are communities and organisations. In the example of the nature system and the technical system, fertiliser use on the farmland could cause eutrophication in the river, which would affect the life in it and around it. To assess these effects, according to Tivander et al. (2010), the social system would have to understand what aspects of the technical system is causing the effects, what value those aspects provide, and what the value of the effects on the nature system is. Even though the model was originally constructed for LCA applications and strictly for environmental issues (Tivander et al., 2010), it was used in this thesis due to the opportunity it provided for structured classification of risk categories. To facilitate the communication of terminology, such structured classification can be useful when creating a conceptual model.

3.3. Procedures for Creating the Model

A model's purpose, according to Van Leeuwen and Vermeire (2007), is to facilitate the understanding of complex parts of reality. By creating a model, certain cause-effect relationships can be identified, that would have been difficult to distinguish from the initial data. It is therefore important to connect identified risks in the supply chain by creating these cause-effect chains, examples of which can be found in the methodology for LCA.

The systematic approach used in environmental LCA can be used to identify the product's process steps, the stakeholders connected to those, as well as the potential environmental impacts from each phase (Breedveld, 2013). Even if according to Baumann and Tillman (2004) risks are usually not included in an LCA, Breedveld (2013) states that by combining the LCA approach with risk assessment (RA), risks can be discovered in the entire life cycle. In an LCA, impacts on objects at risk can be estimated, while RA evaluates potential risks caused by risk objects (Harder et al., 2015). By integrating the LCA approach in RA, risks can be assessed in different parts of a products' life cycle, in various locations where production processes occur (Harder et al., 2015). Both tools can be used in environmental management, by aiding in decision-making processes, contributing with different kinds of information (Harder et al., 2015).

In both environmental LCA and in RA, the connection of impacts and objects at risk can be modelled by linking cause-effect chains (Harder et al., 2015). Baumann and Tillman (2004) illustrate the complexity in environmental impacts as seen in Figure 3, showing a web-like structure of cause-effect chains, forming a cause-effect cascade.

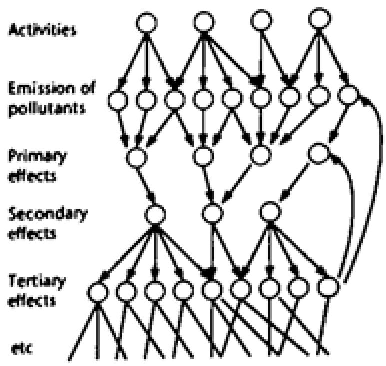


Figure 3. Illustration of cause-effect cascade (Baumann & Tillman, 2004)

In one of the later steps in an environmental LCA, indicators are used to quantify environmental impacts (Baumann & Tillman, 2004).

There are also social risks connected to the lifecycle of a product, which can be identified through social life cycle assessment (S-LCA) (Moltesen et al., 2018). Popovic & Kraslawski (2015) states that a difference from environmental LCA is that stakeholders are of great importance and stakeholder involvement is high since they are what the social impacts affect. The main purpose of S-LCA is to assess negative impacts on stakeholders' well-being

(Moltesen et al., 2018). This causes problems with data collection, which has been acknowledged by several of the identified company tools described in the background. Moltesen et al. (2018) argues that, in contrast to conventional LCA, S-LCA cannot rely on using generic databases. According to Moltesen et al. (2018), it needs site-specific data in combination with the national and regional context in which the company operates. It might also be difficult to reach other suppliers than the first tier, since lower tiers might be reluctant to give out information that could expose the potentially adverse effects of their operation (Moltesen et al., 2018). However, there are some databases similar to the ones used in environmental LCA, with compiled data of social risks and impacts, for example the Social Hotspots Database (SHDB) (Benoît Norris, 2014). According to Benoît Norris (2014), data included in the SHDB should fulfil certain criteria, such as comprehensiveness, legitimacy of data sources, availability of quantitative indicators, and data that captures what is investigated.

Nevertheless, according to Beer et al. (2019) it is easier for companies to provide data on specific targets, such as a zero-emission target, compared to targets regarding working hours or workplace environment for instance. De Beer et al. (2019) also argue that environmental impacts often have linear relationships, whereas social impacts are non-linear. This can be illustrated by comparing a reduction in emissions, which will be regarded as an improvement, compared to fewer children working (de Beer, et al., 2019). Any number of children working will be considered unethical and socially unsustainable.

3.4. External Perspectives

To get an external perspective on environmental and social risks that could occur in Volvo Cars supply chain, five Non-Governmental Organisations (NGOs) were selected to be investigated: Amnesty International, the Human Rights Watch, Greenpeace, the World Wildlife Fund (WWF), and United Nations Global Compact (UNGC). Since these NGOs do not view environmental and social issues from a business perspective, they provide a different view of risks related to them. Most NGOs are private, non-profit organisations that are not government affiliated, and they address local, national, or international matters such as human rights and environmental protection. Generally, they are not criminal, violent, or political parties (Karns, n.d.).

Amnesty International is a global movement whose work aims to terminate human rights abuses (Amnesty International, 2022-a). According to their website, Amnesty fights these abuses worldwide by engaging in detailed research and campaigning (Amnesty International, 2022-b). Their view on corporate accountability includes both the opportunities created and the harmful consequences that can impact a local community (Amnesty International, 2022-c). Human rights issues with green transition towards electrification has been raised previously by Amnesty (2021). The organisation urges businesses to prioritise governance of their battery supply chains, since they contain a list of potential environmental risks and human rights violations (Amnesty International, 2021).

Another NGO that focuses on human rights issues, is the Human Rights Watch. The organisation investigates if human rights are abused, exposes potential human rights violations, and pushes for changes in legislation and policies to prohibit such instances (Human Rights Watch, 2022-a). Amongst other issues, Human Rights Watch (2022-b) investigates how oil, mining, and gas industries connect economic development of countries with abuses, relocation of local people, and the fuelling of governmental corruption.

A more environmentally focussed NGO is Greenpeace. They state that their mission is to prevent biodiversity loss and pollution everywhere on Earth, as well as other forms of abuse of the air, land, ocean, and freshwater. They also want to promote peace, non-violence, and the ending of nuclear threats (Greenpeace International, 2022-a). The three areas which are important to Greenpeace is *Energy, Nature*, and *People*, and they emphasise the importance of renewable and sustainable energy, the climate and biodiversity, and people helping each other overcome the current disparities.

Another NGO with focus on the environment is WWF, which states that their mission is "to conserve nature and reduce the most pressing threats to the diversity of life on Earth". To do this, they work in six areas: *food, climate, freshwater, wildlife, forests*, and *oceans* (World Wildlife Fund, 2022-a). Additionally, they also mention eleven threats which impact the Earth and its biodiversity (World Wildlife Fund, 2022-h).

The UNGC is a corporate sustainability initiative that touches upon both environmental and social issues. They urge companies to apply universal principles on human rights, labour, environment, and anti-corruption to their strategies and business operations (United Nations Global Compact, 2022-a). By getting corporations to provide annual reports on their achievements and engage themselves in the communities they operate, UNGC wants to create corporate sustainability (United Nations Global Compact, 2015). They do this by guiding companies to operate responsibly and achieve their commitments (United Nations Global Compact, 2015).

4. Methodology

This thesis consisted of both creative processes, such as creating and designing a usable framework for the model, as well as searching literature and having discussions to gather information. Concepts were defined to create a shared understanding among the internal stakeholders at Volvo Cars, and together with their opinions, external perspectives were investigated to develop a comprehensive model.

4.1. Creating the Model

The process of creating the model involved several steps, such as compiling the collected information from literature and interactions with internal stakeholders. Even if the developed model did not result in a finished tool, the model in its current state was tested in the final steps with a case study.

4.1.1. Construction of the Model

To generate risk categories for the model, objects at risk, risk objects, and links of relationships of risk were collected from interviews and meetings with internal stakeholders at Volvo Cars and by using literature. The procedures of the interviews and meetings with the internal stakeholders will be described further in *4.1.2. Collecting Information.*

When identifying the risk categories stated in the literature and conversations with internal stakeholders, the explicitly mentioned ones were extracted first. The literature and answers from interviews were then interpreted to extract risk categories that were mentioned more implicitly. To group the resulting categories, they were divided into objects at risk, risk objects, and links of relationship of risks, according to the definition by Boholm and Corvellec (2011). This procedure was done to facilitate future steps in the creation of the final model, the identification of cause-effect-chains. In this thesis, the model starts with an activity (risk object), triggering different impacts and effects, i.e., relationships of risk. The chain of consecutive risk relations eventually encounters the object at risk, causing some type of harm.

Based on the three systems: *The Nature System*, *The Social System*, and *The Technical System* by Tivander et al. (2010), the structure shown in Figure 4 was created. This division was chosen since it would structure the model, easing the identification process of different types of risks. When making this categorisation, it was decided to focus on the objects at risk, since clarifying what Volvo Cars prioritises to protect would ease the selection of risk categories for the final model.

System	Level 1	Level 2	Level 3	Level 4
1. Nature System	1.1. ...	1.1.1. ...	...	...
		1.1.2. ...	...	...
	1.2. ...	1.2.1. ...	...	...
	...	...	...	...
2. Social System	...	...	...	...
	...	...	...	...
	...	...	...	...
3. Technical System	...	...	...	...
	...	...	...	...
	...	...	...	...

Figure 4. Structure used for organising the identified objects at risk.

Having categorised them into *The Nature System*, *The Social System*, and *The Technical System*, it was possible to create a system of, what was chosen to be called, "Levels" for the objects at risk as shown in Figure 4. It went from Level 1 to Level 4 and the detail of the objects increased with every subsequent level. The decision of what level each object at risk would be placed on was decided through the authors' discussions, trying to compile objects at risk based on their level of detail. The result from this categorisation was used in a workshop, where the aim was to reduce the number of collected risk categories.

The workshop was held with relevant employees to reduce the number of objects at risk at level 2 in the model to 15-20 objects. The workshop format enabled semi-structured discussions, focusing on a few specific topics. There were two reasons for choosing 15-20 objects at risk at total. Firstly, it approximately matched the number of categories used in Apple's (2019) and Nike's (2012) assessment tools and, secondly, the number of objects at risk needed to be in a manageable range to make the model useful. The workshop procedure is described in *4.1.2. Collecting Information*.

When creating the final model, the resulting 15 second level objects at risk from the workshop were used. It would have been too time consuming to use the objects at level 3 or 4 since they are on a much more detailed level. By only focusing on the remaining objects at risk at level 2, several risk objects and links of relationships of risk generated from the interviews and literature studies could be eliminated in the process of creating cause-effect chains. In the procedure of creating the chains, risk objects posing a threat to the object at risk in question were linked together by inserting relevant elements of risk as is illustrated in Figure 5. The model is read from left to right, starting from the object at risk and ending up with a risk object at the right side. However, the cause-effect chains are followed from right to left, and the final elements of risk are the ones in boxes since they were the ones used as a basis for finding indicators.

The chain of risk relations was decided to consist of one, two, or three elements of risk in total to get a manageable model. In reality the chains can extend significantly in length. When identifying gaps between an object at risk and a risk object, the authors alone discussed suitable options to complete the chains. These decisions were based on previous knowledge about the interaction between different impacts and effects they potentially cause.

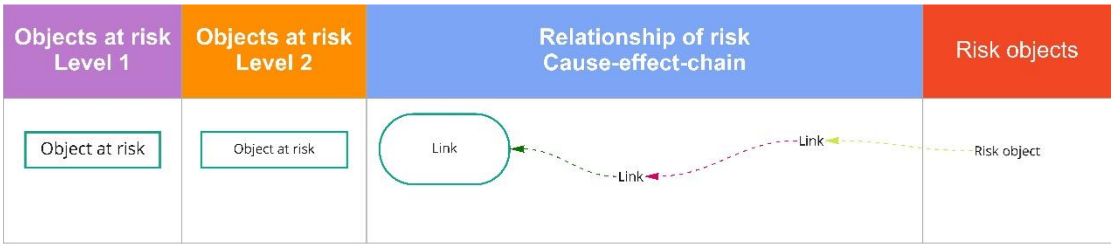


Figure 5. Illustration of the connection of an object at risk with a risk object, and the links of relationships of risk.

4.1.2. Collecting Information

First, in order to discuss and identify risk categories, three meetings with relevant employees at Volvo Cars were held. The meetings boiled down to the employees being shown the list of risk categories as it stood at the time, and them suggesting additional categories relevant to their field. The list was then complemented with the additions the employees made, and then they were sorted into the appropriate risk category. The first of these sessions was also used to collect risk definitions.

What separated these sessions from the interview format was that they were more of a free discussion regarding risk categories, for the attendees to get used to the way of thinking and to get more perspectives on the matter. Except from the first session, which was more organised, these sessions did not include specific questions for the attendees to answer but was a way to check their opinions on the matter. They were done to involve more people and expertise into the project, to get a broader knowledge base than was already possessed among the authors. These sessions were held before the *Relational Theory of Risk* (Boholm & Corvellec, 2011) had been introduced to the employees.

After a while it became evident that there was a need of a more structured way of having these conversations. It was decided to use the interview format to gather information about Volvo Cars' internal perception of different risk categories, but also to define the concepts of risk and sustainability. By using prepared questions, the outcome of the interview could be more easily monitored. If a questionnaire had been used, there would be a risk of not receiving answers from every selected stakeholder. The interview format forced direct as well as intuitive answers from the interviewees. The questions chosen were to some extent based on the articles *Company Risk Management in Light of the Sustainability Transition* (Schulte & Hallstedt, 2018) and *Strategic Sustainability Risk Management in Product Development Companies: Key Aspects and Conceptual Approach* (Schulte et al., 2020). These were complemented with questions founded on the relational theory of risk by Boholm & Corvellec (2011), that would help define risk categories observed by the employees. The final questions can be found in both English and Swedish in Appendix V. Following a pilot test of the interview questions, twelve interviews were conducted with in total 17 employees from a variety of departments. A list of the participants and their work areas is provided in Appendix VI. Mainly, Microsoft Teams was used when doing the interviews, and each session was recorded and later transcribed.

When conducting the workshop with internal stakeholders at Volvo Cars it was decided to include three exercises. First, the attendees were divided into three groups, corresponding to the three systems, based on their working area. The list of the attendees and their work areas are listed in Appendix VI. The objective of the first exercise was for each group to consider the objects at risk at level 1 and 2 within their system, and decide to either delete, merge, or add objects at risk to reach 15-20 objects at risk in total at level 2. The second exercise was performed individually, where each participant considered the objects at risk from all three systems, while noting the ten objects at risk which they believed to be the most important for the company. Afterwards, the objects at risk which got zero votes were eliminated, and the objects at risk at level 3 and 4 for the remaining list, which were not shown in the first exercise, was made available. For the third exercise, the participants were put back into the groups and were instructed to consider the objects at risk at all levels, but mostly on level 3 and 4, to figure out whether there might be indicators with available data connected to them.

The external company tools described in the background were used to identify risk categories regarding material within their supply chain. Generally, the reports, where the methods or tools were presented, included identified risk categories of some sort, which were added to the model.

For other external perspectives, the NGOs presented in *3.4. External Perspectives* were used for identifying risk categories from a non-business perspective. The NGOs were selected from the website of the Berkley Library, and the information was collected from the websites of the chosen organisations. From the compiled information, risk categories were identified and added to the model.

4.1.3. Final Steps

To quantify risks in the supply chain, the final model needed to contain indicators that show if the potential risk is occurring. After completing the final model, different sources of literature were used to identify indicators for the links of relationships of risk connected to the 15 final objects at risk. With an indicator for a certain object at risk, it would be possible to trace the chain to distinguish the risk object and act against it. The purpose was to identify at least one example indicator for each of the remaining objects at risk. Nevertheless, in some cases additional indicators were found and added to some of the objects. Conducting this process in the final phase of the study did not provide enough time to identify the most suitable indicator, but rather suggestions provided by the sources used for identifying risk categories.

To test the model, a case study was conducted with four Volvo Cars employees who were well informed about the project and the model. It consisted of a comparison of this thesis' model and the contents of the *Material Change* report by Drive Sustainability et al. (2018). Drive Sustainability is an initiative including ten automotive brands, one of them being Volvo Cars (Drive Sustainability et al., 2018). They have assessed the ESG risks related to 37 materials that are commonly used in the automotive and electronic industries (Drive Sustainability et al., 2018). A case study seemed appropriate since it was deemed important to compare the model to a website which is used in the automotive industry in general, to see that the model could be at least equal. But mainly, it was an assessment of the final model itself. As a limitation, the compilation only focussed on two materials: aluminium and natural rubber.

4.2. Defining Sustainability and Risk

Definitions of core terminology were produced to improve clarity and consensus in the model. Both literature and answers from the interviews with the internal stakeholders were used when determining the two core concepts: sustainability and risk. When defining sustainability, the Brundtland definition (United Nations, 2022-b) was compared to Volvo's view on sustainability.

The second ambiguous concept crucial to this study was risk, which, as well as sustainability, can be interpreted in several ways in different contexts and by different observers. Since the risk terminology used in this study was based on the relational theory of risk, the definitions listed by Boholm & Corvellec (2011) were compared to the risk definition from ISO 31000, the international standard for risk management.

To further explore Volvo Cars internal approach, the interviewees were asked to define both risk and sustainability. After stating their personal view on how to define each concept, it was asked whether they considered those to be shared by Volvo Cars as a company. The answers were then compiled into two tables, one for each definition to compare their similarities and differences.

The result from the literature studies and the interviews with internal stakeholders was used to produce this thesis' final sustainability definition and risk definition. By using key words that occurred at a high frequency in the results of each concept, two general definitions were created to include the terms seeming the most relevant to the authors. Words with the same or similar significance were grouped together and regarded as a united concept. If the same reference or interviewee repeated certain key words or terms that were compiled into one concept, they were still only counted once.

5. Results and Discussion

The most important outcome of this thesis is the developed model and the risk categories it includes. Besides that, several insights were gained throughout the process and conversations with the internal stakeholders at Volvo Cars. Succeeding all discussions, the importance of having a shared terminology became evident, which can be viewed as a result in itself. Lastly, two definitions were produced in this study, one for sustainability and one for risk.

5.1. The Final Model

By using the relational theory of risk by Boholm and Corvellec (2011), the entire cause-effect chain is included in the finished model, contributing to a more holistic perspective than the tools provided by the other companies. It includes both objects important for Volvo Cars to safeguard, as well as what they want to avoid. Hence, when an object at risk has been identified and a connected link of relationship of risk confirmed, the model helps tracing the chain to the risk object, enabling management of that specific risk object. Since the model is that extensive, some parts might be deemed superfluous. For example, all identified risk objects might not be possible for Volvo Cars to affect or mitigate. However, keeping them in the model acknowledges their importance.

The final model, constructed in MIRO, is shown in Appendix XV. It is explored in more detail in the following sections. Level 3 and 4 are not part of the final model, but rather describes what is included in each category, since they are on a very detailed level. All identified risk categories are listed in Appendix I-IV and VII.

5.1.1. The Nature System

Figure 6 shows an example of some cause-effect chains connecting *Atmosphere*, one of the levels under *Climate*, to its risk objects. The model is read from left to right, starting with the object at risk, followed by the effects that could potentially cause harm. The cause in the cause-effect chain is seen in the blue column in the middle. The arrows are following the opposite direction solely to indicate which effects are caused by certain risk objects, which are found in the right side of the model.

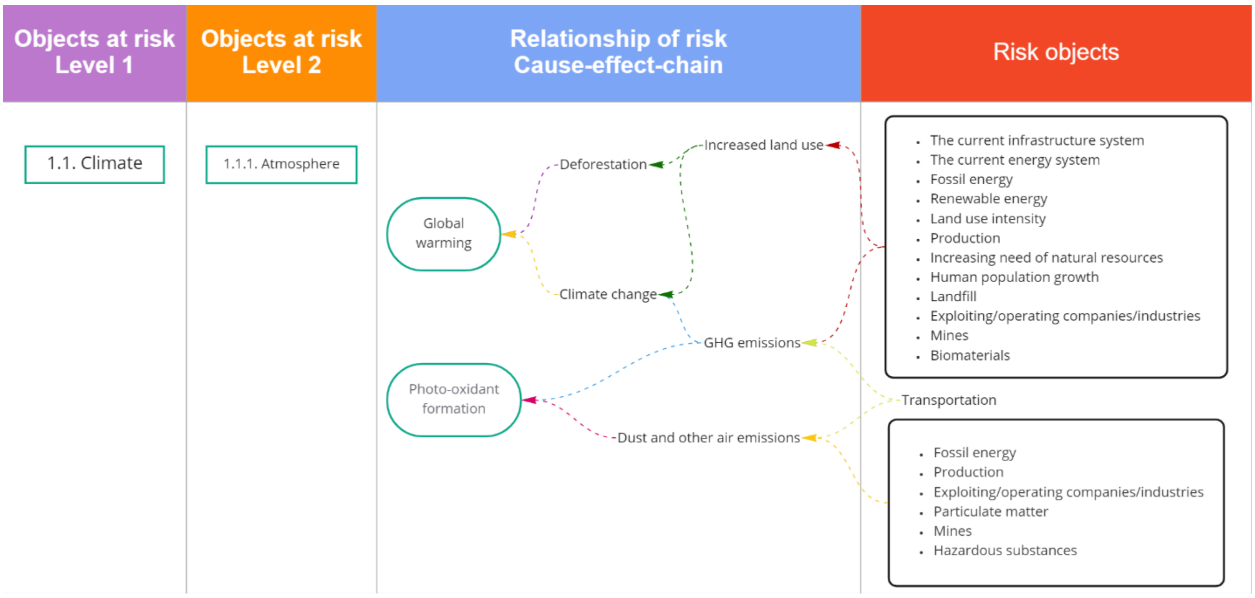


Figure 6. Example of cause-effect chain for Atmosphere as an object at risk in the Nature System.

5.1.1.1. Climate

Climate includes *Atmosphere, Ocean, Freshwater,* and *Land & Soil* as objects at risk at Level 2.

Atmosphere

The category *Atmosphere* contains additional objects at risk at Level 3, such as the stratospheric ozone layer, low CO_2-concentrations, and albedo. On Level 4, stratospheric ozone is included in the stratospheric ozone layer, and clouds are included in albedo. Risks related to the atmosphere were mentioned as highly important in literature, by NGOs and other companies, as well as the internal stakeholders at Volvo Cars. Some of the risk relations frequently mentioned were global warming, climate change, and GHG emissions. Those were most often thought to be caused by transportations and operations related to extraction and production processes of the company, but also people in power making important decisions.

Regarding the NGOs, climate change and global warming were mainly discussed by Greenpeace, WWF, and the UNGC, who seemed to have a shared perception. Greenpeace (2022-c) identified energy systems, agricultural systems, and other operating companies to be risk objects, causing for example deforestation, which in turn triggers global warming and climate change. The UNGC (2022-f) stated the same but in different terms, and WFF (2022-c) added current food production systems and forestry to the list of risk objects.

Global warming and GHG emissions were mentioned by Filippa K (2021), GM (2021), and Stella McCartney (2020), in their respective tools. Energy use seemed to be the main risk object causing those risks according to the investigated companies.

The literature also touched upon GHG emissions and global warming. However, they did not in detail provide specific objects at risk or risk objects.

When interviewing the internal stakeholders at Volvo Cars, emissions from operation processes and transportation were by far the most frequently mentioned risk relations, and climate one of the most prioritised objects at risk. The fact that they were thinking a lot about climate-related issues, can be connected to Volvo Cars three pillars of sustainability. One of the pillars describes their aim of being climate neutral by 2040, thus, it can be assumed that questions about climate is integrated in their daily work. Even when defining sustainability, many of the internal stakeholders relied on the three pillars, highlighting the importance of the climate itself and climate change.

Connecting all risk objects related to the atmosphere through the links of relationships of risk, the final risk relations in the cause-effect chains (see Appendix XV) used for searching indicators were *Global warming, Photo-oxidant formation,* and *Depletion of stratospheric ozone.* Despite the limited time, it was possible to find indicators for each risk relation, which can be seen in Appendix XVI. All of them, Global Warming Potential (GWP), Ozone Depletion Potential (ODP), and Photo-oxidant Creation Potential (POCP), are used in LCA and were found in *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004).

Ocean

Ocean does not have any objects at Level 3 or 4 but does still have several risks related to it. It was not explicitly stated as an important object at risk, but there were many highlighted risk relations which could be connected to the ocean. The interviews mentioned indirect risk relations such as GHG emissions, global warming, and toxicity, while NGOs, additional companies, and the literature also stated more explicit risk relations such as eutrophication, acidification, and water pollution.

The NGOs, mainly Greenpeace, WWF and UNGC, highlighted global warming and climate change for this object as well, which both could be connected to ocean acidification. These risk relations were suggested to be caused by components of the technical system, such as energy systems, agricultural systems, and other operating companies by Greenpeace (2022-c), UNGC (2022-f), and WWF (2022-c), which also stated forestry and food production systems as risk objects. For other links of relationships of risk, water pollution, contamination and eutrophication, Greenpeace (2022-g) stated waste handling and, together with WWF (2022-c) and UNGC (2022-f), agricultural systems as possible risk objects. Out of all sources, the NGOs were the ones that prioritised *Ocean* the highest, the other sources merely touched upon it through the similarities to *Freshwater*.

For the company tools, climate change, global warming and acidification was suggested to be caused by the risk object energy use (Filippa K, 2021; GM, 2021; Stella McCartney, 2020). Regarding water pollution and eutrophication, Apple (2019) mentioned chemical usage, and Nike (2012), GM (2021) and Stella McCartney (2020) stated waste as risk objects in this matter. Waste could also be connected to microplastics, which Filippa K (2021) stated as a risk relation. Nike (2012) and Filippa K (2021) mentioned different types of toxicity, which could be connected to waste and chemical usage.

Drive Sustainability (n.d.) was the only literature who suggested a risk object regarding water pollution since it stated hazardous substances. Closely related is toxicity, which the *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004) highlighted some risk objects to by giving examples of different toxicological impacts. Additionally, GM (2021) mentioned landfill as a risk object, and Drive Sustainability (n.d.) mentioned hazardous waste.

Regarding global warming, climate change and acidification, the risk objects mentioned by the interviews were fossil energy, transportation, and production. They also suggested Waste of Electrical and Electronic Equipment (WEEE) and process chemicals as risk objects for toxicity.

In the chain of connected risk objects and risk relations, the final links of relationships of risk (see Appendix XV) used for searching indicators were *Cultural value loss*, *Eutrophication*, *Acidification*, *Toxicity*, and *Pollution*. It was possible to find indicators for most of these, and their description can be found in Appendix XVI. The found indicators were Acidification Potential (AP), Eutrophication Potential (EP) and Marine Aquatic Ecotoxicity Potential (MAETP), all of them retrieved from *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004). For the last two, pollution and cultural value loss, no indicators were found. For pollution, the mentioned indicators are applicable but not for all types of pollution, and for cultural value loss, the session for testing the model concluded that it is a risk relation which is particularly difficult to find indicators for. For these links of relationships of risk, specification is required to find measurable indicators, which might be easier for different chemical pollutions than loss of different cultural values. However, cultural value loss was still deemed important to include despite the lack of indicator, to acknowledge that it happens.

Freshwater

As with *Ocean*, *Freshwater* does not have any objects at Level 3 or 4 but does still have several risks related to it. Most of the findings for freshwater were the same as with ocean, and thus the reader is referred to that section. However, there was one additional risk relations to consider: freshwater scarcity, acquired from the additional company tools. Freshwater scarcity was stated by Filippa K (2021) and Stella McCartney (2020), which might be because of the high water-usage in the production of fabrics and could be linked to the risk object water consumption, which was highlighted by the two mentioned companies, as well as GM (2021). Also in this category, Drive Sustainability (2018) mentioned groundwater use as a risk object. Due to the addition of freshwater scarcity, this object at risk was more talked about outside of the NGOs, which might be due to the use of freshwater in production and that it also affects people to a larger extent, not just water habitats.

The final risk relations were *Cultural value loss*, *Eutrophication*, *Acidification*, *Toxicity*, *Freshwater scarcity*, and *Pollution*. Since most of the final risk relations used for indicators were the same as in the case of *Ocean*, the indicators AP and EP are the same, with the addition of Freshwater Aquatic Ecotoxicity (FAETP), which was also available in *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004). Indicators were not found in the case of freshwater scarcity, pollution, or cultural value loss, for the same reasons as in the Ocean section. They were kept regardless, due to the importance of still acknowledging their existence.

Land & Soil

The category *Land & soil* includes soil fertility on Level 3, which in turn includes soil quality and soil organic matter on Level 4. Overall, the impression gained from literature studies and interviews was that soil related issues were not highly prioritised.

The NGOs considered some risk categories related to land and soil important. Greenpeace did not specifically mention soil as an object at risk, but did however highlight risk relations that could harm it. Deforestation, forest fires, forest degradation, climate change and different types of pollution, were activities that pose a threat to soil and its quality and fertility, raised by Greenpeace (2022-d). In addition, WWF (2022-h) pointed out soil erosion, soil degradation and topsoil loss as links of relationships of risk. A risk relation that differed in connotation was WWF's (2022-e) concern about cultural value loss. Mainly, the risk objects responsible for the damage were thought to be operating companies and industries, but also the increasing need of natural resources.

None of the investigated companies included soil as an object at risk in their tools. Similarly to the NGOs, it was rather the links of relationships of risks that were mentioned that could be connected to soil impacts. Deforestation, global warming, GHG emissions and microplastic pollution were examples of such risk relations. A risk object that was connected to these issues was land use intensity, which was mentioned by three out of the five companies, Nike (2012), Filippa K (2021), and Stella McCartney (2020).

In the literature, soil fertility was identified as an object at risk and raised as an important issue by one reference. Reasonably, it was provided by the Nativa Precious Fiber checklist (2021), which is applied to farming procedures when making wool. Many of the risk relations connected to soil fertility were also added by Nativa (2021), including soil erosion, soil compaction, loss of soil organic matter, and land degradation due to overgrazing. Soil contamination and deforestation where additional links of relationships of risk stated by the *Raw Material Outlook* (RMO) platform (Drive Sustainability, n.d.) and ecotoxicity by Baumann & Tillman (2004). Interpreting the risk objects identified in the literature, the objects posing a threat to soil fertility where identified as operations related to mining and storage and usage of different substances that could potentially impact the soil.

Soil and its properties were not explicitly raised as an important issue when interviewing the internal stakeholders either. Even though certain links of relationships of risk and risk objects compiled from the interviews in fact do affect soil negatively, such as different operational activities, they were mentioned in other contexts concerning other objects at risk. However, the knowledge build-up sessions indicated that there was an awareness of the importance of soil, since soil quality was indeed stated as an object at risk, being exposed to soil quality deterioration.

Following the creation of the cause-effect web for *Land & Soil*, the final links of relationships of risk in the cause-effect chains were *Cultural value loss*, *Forest degradation, Soil quality deterioration*, *Toxicity*, and *Pollution*. Two examples of indicators were selected, both relating to pollution and toxicity: the LCA indicator Terrestrial Ecotoxicity Potential (TETP) (Baumann & Tillman, 2004), and Potential for acid discharge to the environment (Drive Sustainability et al., 2018). Both are described in further detail in Appendix XVI. As with *Ocean* and *Freshwater*, it was concluded that cultural value loss is an important issue, but finding an indicator for it would be a complex task.

5.1.1.2. Ecosystem Services

The second level objects at risk included in *Ecosystem Services* are *Biodiversity* and *Natural Resources*.

Biodiversity

Biodiversity is on Level 3 divided into terrestrial, freshwater, and ocean biodiversity, which in turn consist of legally protected areas and threatened species on Level 4 in each of the three areas. Impacts on biodiversity were often mentioned in the references, as well as in the conversations with internal stakeholders at Volvo Cars.

The NGOs talked about biodiversity in different terms such as flora, fauna, habitats, ecosystems, and different species, but in one way or another it was highlighted as an important issue by Greenpeace (2022-b, -e), WWF (2022-e), and UNGC (2022-f). Greenpeace (2022-d, -e) argued that operational activities pose threats to biodiversity, through forest fires and other types of deforestation. Since WWF’s (2022-e) key question of concern is wildlife conservation, it seemed natural that the organisation prioritises biodiversity, pointing out human activity overall as the risk object. UNGC (2022-f) highlighted climate change as an important risk relation causing biodiversity loss.

Of the companies, the ones that included biodiversity as an object at risk were Filippa K (2021) and GM (2021), and biodiversity loss as a risk relation by Stella McCartney (2020). Other links of relationships of risk that contribute to biodiversity loss were mentioned such as pollution (Filippa K, 2021), deforestation (Stella McCartney, 2020), and different kinds of toxicity (Nike, Inc., 2012). Apple (2019) did not explicitly use biodiversity loss as a parameter in their tool. Risk objects were interpreted to be different operational activities and handling of substances.

As with the NGOs, biodiversity was described with different terms in the literature and was there most frequently mentioned object at risk. Baumann & Tillman (2004), the *Material Change* report (Drive Sustainabilityet al., 2018), and Nativa Precious Fibre (2021) were the references with a more environmental approach and put great emphasis on biodiversity. Besides risk relations already mentioned by the NGOs and the companies, habitat alterations and impacts on biodiversity, overlap with areas of conservation importance, and invasive species in farming were viewed as threatening biodiversity by the three references.

The internal stakeholders at Volvo Cars did give the impression of treasuring biodiversity, frequently addressing it as an object at risk in the interviews. Both the risk relations and the risk objects connected to negative impacts on biodiversity were similar to the ones underlined by previous entities. This is maybe not surprising since biodiversity has been discussed within Volvo Cars recently, due to future corporate reporting requirements

Finally, after creating cause-effect chains the final risk relations were *Species loss/Species extinction, Habitat loss, Cultural value loss*, and *Toxicity*. One of the example indicators generated was the Red List Index (RLI) which is created by the IUCN (IUCN, 2022) and used as an indicator for the UN SDG 15, Life on Land (United Nations, u.d.). As with previous objects at risk, the complexity with finding an indicator for cultural value loss was acknowledged. For a more detailed description or more indicator examples, go to Appendix XVI.

Natural resources

On Level 3 the object at risk *Natural resources* is divided into its three components: natural ocean resources, natural freshwater resources, and natural terrestrial resources. All three are then specified on Level 4, where these resources are split up into biotic and abiotic resources, generating six objects at risk at that level, which are specified in Appendix XIII. This object at risk is not mentioned to a large extent in the sources, but some risk relations connected to natural resources are mentioned.

For the NGOs, regarding the risk relation forest degradation, WWF (2022-f) is alone in stating it explicitly. Greenpeace (2022-e) mentioned deforestation as a risk relation which is one of the causes of forest degradation in the cause-effect chain in the model. Deforestation is also a cause of biotic depletions, to which WWF (2022-h) added topsoil loss as a link of relationship of risk and the current food production system as a risk object. This was supported by Greenpeace (2022-c), who stated agricultural systems as a risk object. All the NGOs highlighted some form of exploiting industry in a way which could link it to depletion. Additional suggested risk objects were increasing need of natural resources (Amnesty, 2022-g; Human Rights Watch, 2022-b), the current energy and food production systems (WWF, 2022-f; Greenpeace, 2022-e), and human population growth (World Wildlife Fund, 2022-d) as risk objects linked to depletion. What separated the NGOs from the other sources is that they regarded *Natural resources* as important to people in general, and not just to companies. This is not too surprising since they do not have a company perspective.

The companies Nike (2012) and Filippa K (2021) explicitly stated different forms of toxicity as risk relations, and were supported by Apple (2019), GM (2021), and Stella McCartney (2020) with their stated risk objects. Apple stated chemical usage as a risk object; GM (2021), Nike (2012), and Stella McCartney (2020) mentioned waste, and GM (2021) added landfill as a risk object. Regarding biotic depletion, land use intensity was mentioned as a risk object by Nike (2012), Filippa K (2021), and Stella McCartney (2020), and the latter also mentioned deforestation. When it came to also including abiotic depletion, Nike (2012) mentioned the risk object energy intensity, while Filippa K (2021) highlighted total energy consumption

For the literature, the *RMO* platform (Drive Sustainability, n.d.) was the sole provider of risk objects connected to toxicity, stating hazardous waste. Regarding forest degradation and biotic depletion, they also mentioned deforestation as a risk relation. Seeing that so few texts in the literature highlighted risk categories related to *Natural resources*, it could be assumed that they did not find it too crucial.

As in the previous two objects at risk, the interviews stated toxicity as a risk relation, with WEEE and process chemicals as risk objects. They also mentioned inefficient material use as a risk relation connected to the depletions. As risk objects in this category, they highlighted energy use, fossil materials, fossil energy and biomaterials, and they were the only ones to mention *Natural resources* explicitly, which proved that it was an important category to them.

After creating and testing the model, the final risk relations were *Forest degradation*, *Biotic depletion*, *Abiotic depletion*, and *Toxiciy*. The indicators that were found for these risk relations were Estimated Rate of Depletion from Drive Sustainability (2018) and Depletion of Abiotic Resources from *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004).

5.1.2. The Social System

The social system contains large categories with very complex cause-effect chains, an example of which is presented in Figure 7. The cause-effect chains in the middle connect the object at risk *Children* at Level 2, included in *Humans* on Level 1 in the left of the figure, to several risk objects positioned at the right side.

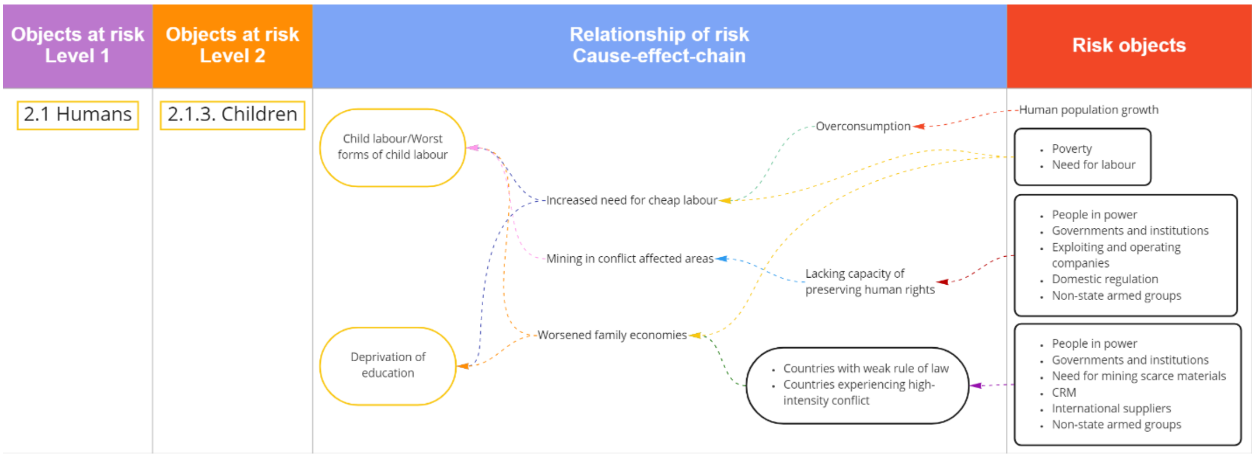


Figure 7. Example of cause-effect chain for Children as an object at risk in the Social System.

5.1.2.1. Humans

Humans include *Workers*, *Community & Indigenous Peoples*, and *Children* as second level objects at risk.

Workers

At Level 3 under this object there are several objects at risk, including workforce facilities, workers' health and safety, worker's freedom of speech and expression, and women and girls. At Level 4 there are objects specifying the health and rights of diverse groups of workers, which are laid out in more detail in Appendix XIII.

The NGOs stated several objects at risk tied to workers, with Greenpeace (2022-f) and UNGC (2022-b) stating workers explicitly. For other objects at risk, Amnesty stated freedom of expression (Amnesty International, 2022-f), Human Rights Watch highlighted women and girls (Human Rights Watch, 2022-f), and Greenpeace (2022-e), WWF (2022-f), and UNGC (2022-g) mentioned human security, which could be specified to regard workers. Risk relations mentioned by the NGOs, and which could be connected to these, were forced labour (Amnesty, 2022-c; Human Rights Watch, 2022-f; UNGC, 2022-b), corruption (Amnesty, 2022-c; Human Rights Watch, 2022-b), and pollution (Greenpeace, 2022-g; WWF, 2022-h; UNGC, 2022-g). Through the cause-effect chain, these could be connected to the following risk objects, for example: need for labour (Amnesty, 2022-d; Human Rights Watch, 2022-e; UNGC, 2022-g), and exploiting companies (Amnesty, 2022-c; Human Rights Watch 2022-b; Greenpeace, 2022-b; WWF, 2022-f; UNGC, 2022-b). Objects at risk connected to workers, and their health and rights, were important for all NGOs, which was not surprising since they all have humans or nature as their top priories.

The additional companies also explicitly highlighted workers (Stella McCartney, 2020) as an object at risk, while adding migrant workers (Stella McCartney, 2020) and right to free association (Filippa K, 2021). Mentioned are also several links of relationships of risk threatening the objects at risk. Nike (2012) and Filippa K (2021) stated several types of toxicity affecting workers' health, and Filippa K (2021) also mentioned forced labour. Risk objects at the beginning of the cause-effect chain were mentioned by Apple (2019) and were political instability in producing country and reserve holding country. These were just examples of the risk categories, which shows how important it was for these companies.

The literature mentioned several objects at risk connected to workers' rights and health, where *Nativa Precious Fiber* (n.d.-b) highlighted liberty and freedom of speech. Drive Sustainability's *RMO* (n.d.) and the *Material Change* report (Drive Sustainability et al., 2018) mentioned accommodation and access to water, which is important for worker's health, and the *Methodology Report Product Social Impact Assessment* (Goedkoop et al., 2020-b) highlighted job satisfaction. Some of the potential threats to these objects at risk were the risk objects noise and vibrations (Bauman & Tillman, 2004; Drive Sustainability, 2018) and non-state armed groups (OECD, 2022). Connecting the previous risk categories were many risk relations, where some examples were corruption, mining in conflict affected areas (Drive Sustainability, 2018), discrimination (Goedkoop et al., 2020-a), bribery and fraud (OECD, 2022), and toxicological impacts on human health (Baumann & Tillman, 2004). Once again, since these only were examples, it was clear that workers was an important object at risk in the literature as well.

The interviews mentioned workers explicitly as an object at risk and touched upon workers' health with the object at risk human health and well-being. Links of relationships of risk that the interviewees highlighted which could be connected to this were, for example, bad working conditions and untraced supply chain. These could be connected to risk objects such as mines and international suppliers. Regarding workers' rights the interviews mentioned human rights, which could be specified to the worker subgroup, and the highlighted links of relationships of risk were untraced supply chain and modern slavery. The chain of risk relations connected the objects at risk to some risk objects which the interviews stated: international suppliers and supplier data. In the interviews, problems regarding workers were some of the most noted, indicating its importance.

Notable for this object at risk was that the knowledge build-up sessions provided some key risk categories. The added objects at risk were whistle-blower, connected risk relations were illicit work without residence permit and rising populism. Added risk object connected to other risk relations were workplace temperature, and hazardous substances used in the recycling process. Since workers were important for these meetings as well, it could be concluded that this category was very important to the sources overall.

The final links of relationships of risk were *Safety issues*, *Health issues*, *Harassment*, *Inequality*, *Forced labour*, and *Job insecurity*. The indicators that were found for the remaining risk relations were all quite accessible and are mostly tied to safety issues, health issues and forced labour. The found indicators are Child labour and forced labour from Drive Sustainability, Labour rights and workers safety from UN's 17 Sustainability Goals, and Human Toxicity Potential (HTP) from *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004).

Community & Indigenous Peoples

For this category, there are a great number of objects at risk on Level 3, such as health and safety, livelihood, cultural heritage, material and immaterial resources, freedom of speech, institutional capacity, and the access to renewable and/or carbon neutral energy. Each of these categories consists of additional objects at Level 4, concerning the state of the community or

Indigenous land. For the full list see Appendix XIII. *Community & Indigenous Peoples* is one of the most extensive categories in the model, which resulted in a complex cause-effect web with a great number of risk relations.

Local people was the only object at risk mentioned by all five NGOs. Amnesty (2022-c) put great emphasis on corporate accountability, since they argue that competition over scarce materials between companies are causing land grabbing, pollution, and sometimes corruption in the local community. The Human Rights Watch (2022-b) agreed with the previous statements highlighting the responsibility of oil, mining, and gas industries. Greenpeace (2022-e) discussed the negative impacts of deforestation and logging on Indigenous land, which was also supported by WWF (2022-f). The UNGC (2022-g) indicated more indirectly that local and Indigenous people are exposed to harm by water pollution and scarcity, caused by industrial operations.

Of the identified company tools, only GM (2021) acknowledged local community as an object at risk. GM (2021) also urged for livelihoods as something important to protect, which Stella McCartney (2020) agreed on. Additionally, the latter emphasised the importance of human health and wellbeing. Links of relationships of risk and risk objects stated by the companies were similar to the ones expressed by the NGOs.

The *RMO* (Drive Sustainability, n.d.) provided a range of objects at risk related to *Community & Indigenous Peoples*. Community health and safety, livelihood, and cultural heritage are examples of such. The latter was also presented by Baumann & Tillman (2004), along with human health. Nativa Precious Fiber (2021) provided essential categories such as liberty and freedom of speech. The majority of links of relationships of risk connected to *Community & Indigenous Peoples* were stated by the *RMO* (Drive Sustainability, n.d.) and the *Material Change* report (Drive Sustainability et al., 2018), since they covered many social matters compared to several of the other references.

When interviewing the internal stakeholders, human wellbeing was the most frequently mentioned object at risk, even more frequently than profit, climate, and production. In several interviews, issues with the supply chain were pointed out as risk relations. Examples of that were untraced supply chains, voluntary reporting, and misinformation, enabling human rights violations affecting human health in local communities.

The final risk relations used for finding indicators were *Freshwater scarcity*, *Worsened family economics, Cultural value loss, Health issues, Resettlement & displacement*, *Inequality*, *Safety issues*, and *Harassments*. Even if, as mentioned before, it could be complex to find indicators for cultural value loss and resettlement & displacement, as many as nine indicators were identified for this category (Appendix XVI), much thanks to the extensive documentation presented in the *Material Change* report (Drive Sustainability et al., 2018). The Human Development Index (HDI) and different subindicators from the Worldwide Governance Indicator (WGI) are two examples. Additionally, Human Toxicity Potential (HTP), an LCA indicator, was retrieved from Bauman & Tillman (2004).

Children

At Level 3 under this object at risk, are children's health and safety and children's freedom of speech and expression, under which there are several objects at risk at Level 4, listed in detail in Appendix XIII.

The NGOs are the only stakeholders which explicitly highlighted children as an object at risk and it was done by Amnesty (2022-d), Human Rights Watch (2022-c), and UNGC (2022-d).

As related objects at risk, Amnesty stated freedom of expression (2022-d), and Human Rights Watch also mentioned children's education (Human Rights Watch, 2022-c). WWF alone mentioned coastal residents (World Wildlife Fund, 2022-g), and UNGC (2022-c) mentioned human populations of the Global South, which both could be specified to regard children. The suggested risk relations in the cause-effect chain leading to these objects are corruption (Amnesty, 2022-c; Human Rights Watch, 2022-b), child labour (Amnesty, 2022-d; Human Rights Watch, 2022-d; UNGC, 2022-d). The suggested causes of these were the following risk objects: people in power (Amnesty, 2022-c), poverty (Amnesty 2022-C; Human Rights Watch, 2022-d), and exploiting companies (Amnesty, 2022-c; Human Rights Watch 2022-b; Greenpeace, 2022-b; WWF, 2022-f; UNGC, 2022-d). As with workers, this was an important category due to the humanitarian crises child labour entails.

The additional companies did not have as many suggested objects at risk as the NGOs, with Stella McCartney (2020) being the only one stating human health and human well-being, which could be specified to children. As risk objects, Apple (2019) stated political instability in producing countries and in reserve holding countries. Other than that, different types of waste were mentioned by Nike (2012), GM (2021), and Stella McCartney (2020), which could be connected to the different types of toxicity which Nike (2012) and Filippa K (2021) highlighted. Additional risk relations stated by the companies were hazardous waste (Nike, Inc., 2012), corruption and conflict (Apple, 2019; Filippa K, 2021) and child labour (Filippa K, 2021). This was a significant category according to the companies, but they did not mention as many risk categories as for workers, which shows that they had quite a different point of view from the NGOs, probably because they do not have the same humanitarian focus.

For objects at risk which the literature suggested for this category, *Nativa Precious Fiber* (n.d.-b) mentioned liberty and freedom of speech, *The Hitch Hiker's Guide to LCA* (Baumann & Tillman, 2004) highlighted human health, and Drive Sustainability (2018) stated access to water. Suggested risk object threatening the objects at risk were noise and vibrations (Baumann & Tillman, 2004), non-state armed groups (OECD, 2022) and artisanal and small-scale mining (Drive Sustainability, 2018). These were connected through a cause-effect chain of the following stated risk relations: child deprived education and child labour (Drive Sustainability, 2018), support of armed groups (OECD, 2022), potential harm from hazardous materials and chemicals, and preconditions for radioactive materials in ores and tailings (Nativa Precious Fiber, n.d.-b).

Human health and well-being, and human rights, which both could be specified to children, were some of the objects at risk connected to children mentioned in the interviews. The risk objects threatening these objects at risk were, among others, mines and international suppliers. Some of the risk relations connecting the other risk categories, which the interviews suggested, are untraced supply chain and modern slavery.

The knowledge build-up sessions provided some risk categories for this object at risk, as it did for workers. They added objects at risks such as access to water and access to education, risk relations such as worst forms of child labour, and risk objects like noise. Since all types of sources provided many risk categories regarding children, it could be regarded as an important object at risk, especially since many of them can be seen as worse when they regard children and not just workers.

The final model, then, has these final risk relations: *Child labour* or *Worst forms of child labour*, *Deprivation of education*, *Child marriage*, *Inequality*, *Health issues*, *Harassments*, *Freshwater scarcity*, and *Safety issues*. Two indicators were found, they were accessible, and they are Child labour and forced labour (Drive Sustainability et al., 2018) and Human Toxicity Potential (HTP) (Baumann & Tillman, 2004).

5.1.2.2. Business

The only object at risk on Level 2 included in *Business* is *Supply Chain*.

Supply Chain

Supply chain as an object at risk is composed of suppliers, legal compliance, critical raw material use, and international relations on Level 3. These in turn consist of Level 4 objects at risk, regarding the traceability and transparency of the supply chain, tax payments and licenses, demand, and relations to countries with various importance. From a company perspective, this category appeared to be highly prioritised, having great significance for a company's ability to deliver a product. In contrast to the *Nature System*, the supply chain object is more closely related to a business perspective, which might be why it was applied to this category. Objects in the *Nature System* are not always as directly linked to the company's performance as the supply chain. Therefore, when interviewing internal stakeholders at Volvo Cars, who are probably more business focused when being at work, their business perspective contributed to emphasise the importance of the supply chain as an object at risk. On the other hand, the NGOs did not necessarily care for the supply chain as such. They put greater emphasis on the people included in the supply chain, along with working conditions and health.

None of the NGOs considered the supply chain to be an object at risk. On the contrary, exploiting and operating companies and industries which are part of the supply chain were seen as risk objects by all five NGOs (Amnesty International 2022-c; Human Rights Watch, 2022-b; Greenpeace International, 2022-c, -d, -e; World Wildlife Fund, 2022-f). The need of natural resources was viewed as a risk object, posing a threat to both Indigenous Peoples who lose their land, and children who might be used for labour (Amnesty International, 2022-g; Human Rights Watch, 2022-c). Risk relations connected to the supply chain were for example gaps in knowledge and governance and legislative frameworks that are not efficient (United Nations Global Compact, 2022-e), which can enable different violations.

Stella McCartney (2021) was the only company referring to supply chain as an object at risk, calling attention to fair working conditions and treatment of the people working there. Other companies implied through their stated risk relations that they wanted to safeguard their supply chain. For example, Apple (2019) mentioned limited global production as a risk, and political instability in supply countries as a risk object together with the geographic concentration of reserves and production.

Reviewing the formative literature, the *Material Change* report (Drive Sustainability et al., 2018) provided several objects at risk concerning the supply chain. Legal compliance, social license to operate, and tax payments were some of them. Volvo Cars' (2021-a) presentation about sustainability raised transparency and traceability in the supply chain as something worth protecting. Risk relations that threaten these valuable objects were stated as mining in conflict affected areas, countries with weak rule of law or experiencing high-intensity conflicts, and corruption (Drive Sustainability et al., 2018). Causing these events to happen were described by Drive Sustainability (2018) as dependency on imported material, and by OECD (2022) as non-state armed groups. Hofmann et al. (2013) mentioned boycott as a sypply chain risk. The risk relation was interpreted by the authors to be bidirectional, since customers boycotting the company poses a threat to the company's suppliers, affecting their sales and companies boycotting suppliers due to their, for example, unsufficient sustainability goals is also harming the supplier.

Interviewing the internal stakeholders at Volvo Cars who often applied a company perspective, it was clear that the supply chain was considered important to protect since many risk relations connected to different kinds of suppliers were highlighted. A risk relation that was frequently mentioned by the stakeholders, that could be connected to both the company brand and the selection of suppliers, was the risk of not reaching certain sustainability goals. It was regarded as an issue that could damage Volvo Cars image, which in turn affects the suppliers doing business with the company, resulting in high costs. On the other hand, suppliers not reaching sustainability goals risk to be opted out from the company's supply chain. The interviewees identified that the risk object in this case could be sustainability goals themselves. Having very strict goals with high ambitions that are difficult to reach were viewed as an obstacle rather than something positive. Other risk relations mentioned were untraced supply chains and voluntary or dishonest reporting, which were viewed to be accelerators for other risks in the supply chain. Those could also be caused by other risk objects such as having long supply chains. Such risk relations could result in adverse media, damaging the company brand. It was also discussed whether having requirements for global reach could be viewed as a risk object, preventing the development of small suppliers who do not achieve those requirements. Delivery problems, suppliers not living up to standards, and production stop are some examples of additional risks that were stated as important by the interviewees.

Following the modelling of the cause-effect chains the final risk relations in the cause-effect chain were *Boycott, Not getting primary material, Production stop, High costs,* and *Development prevention (of small, local suppliers)*. Two suggestions of indicators were picked from the *Material Change* report (Drive Sustainability et al., 2018): Function criticality and Dependency – EU/US import reliance rate. Both are described in further detail in Appendix XVI.

5.1.3. The Technical System

An example of how the *Technical System* looks in the final model, can be seen in Figure 8. In the left side of the figure is the object at risk *Scarce materials*, which is a Level 2 object under *Materials and Supply Chain* on Level 1. The model is read from these objects at risk in the left, through the cause-effect chains in the middle, leading to the risk objects at the right side. On the other hand, the cause-effect chains go from right to left, and the final links of relationships of risk are in boxes since they were the ones which the search for indicators was based on.

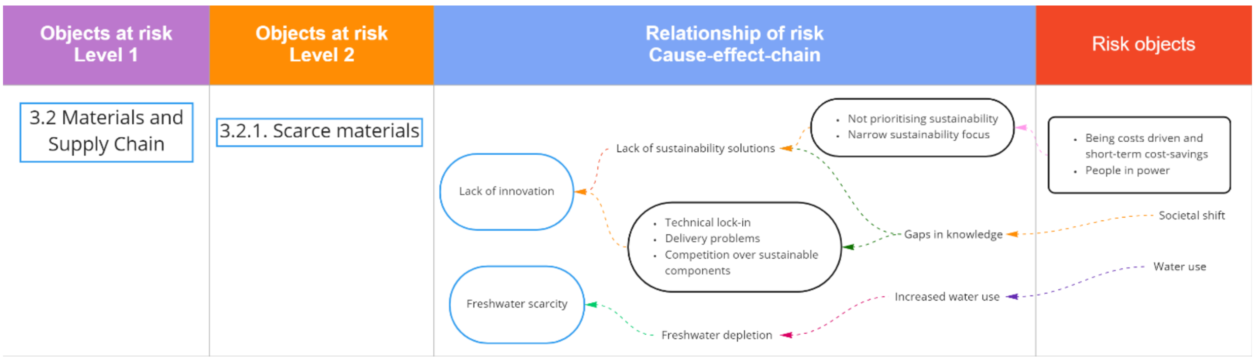


Figure 8. Example of cause-effect chain for Scarce Materials as an object at risk in the Technical System.

5.1.3.1. Product

The product produced by Volvo Cars is naturally highly prioritised among internal stakeholders. The Category includes one object at risk at Level 2 – *Product Quality*.

Product Quality

Included on Level 3 in *Product Quality* are the two objects at risk product longevity and material properties. The sublevels include energy efficiency and durable materials on Level 4. Since this object at risk is mainly observed from a company point of view, product quality was not regarded as an object at risk by any of the NGOs. Since their core issues do not focus on businesses interests, this was hardly surprising.

More surprisingly, none of the investigated companies did explicitly consider the product quality to be an object at risk. It can be assumed that product quality is that essential to a company's existence that it is not needed to be mentioned. However, risk relations and risk objects threatening the product quality were present in, at least, Apple's (2019) materiality assessment methodology. Limited substitutability of materials, corruption and conflict were mentioned by Apple (2019), which were interpreted to affect the company's ability to produce high quality products. This could be caused by for example political instability in producing and reserve holding countries (Apple Inc., 2019).

The formative literature did not highlight product quality as an object at risk either, but rather focused on environmental and social matters. Drive Sustainability (2018) mentions countries with weak rule of law or experiencing high-intensity conflicts or corruption as risk relations, which can be argued to affect a company's material or component access, in turn affecting the product quality.

Volvo Cars' internal stakeholders raised product quality as protection worthy both explicitly and by discussing different aspects such as the product itself, battery lifetime, components, and manufacturing. Risk relations that were raised related to those objects were for example suppliers not living up to standards, delivery problems, not having any fallback material, and competition over sustainable components. Quality degradation and devaluation were discussed as a risk relations connected to the introduction of, for example, recycled materials or banning certain substances without having identified a substitute.

The final risk relations used for identifying indicators that were left in the model were thereby *Reduced material performance*, *No fallback material*, *Lack of innovation*, *Shorter product lifecycle*, and *High costs*. Lack of innovation could be a complex issue for identifying indicators, but as for *Supply Chain* in the social system, function criticality and dependency – EU/US import reliance rate were suggested as indicators. They are described in further detail in Appendix XVI.

5.1.3.2. Materials and Supply Chain

Scarce materials, *Circular and non-renewable materials*, and *Extraction and refining processes* are the objects at risk at Level 2 included in this category. Scarce, circular, and non-renewable materials were categorised into the technical system, since they are evaluated from technical point of view. The risk relations connected to them concern the risks with using and being dependent of these kinds of materials producing the company's products. When the production depends on certain materials, risks threatening the continuous availability of these materials have to be taken into account.

Scarce Materials

The object at risk *Scarce materials* is divided into mined and non-mined scarce materials at Level 3. The mined ones refer to scarce rare-earth elements and metals on Level 4, while the non-mined includes freshwater. Since this category is mainly viewed from a company perspective, NGOs focus more on the issues with accessible freshwater, while the most part of the links of relationships of risk were generated by the internal stakeholders at Volvo Cars.

Freshwater in relation to companies' operations was mentioned by the UNGC (2022-g). According to them, it mainly concerned reputational risks for a company that causes water pollution. This implied that for industries to continuously use water, companies need to evaluate their water performance (United Nations Global Compact, 2022-g). One risk relation connected to freshwater use was freshwater depletion, where one risk object was determined to be exploiting and operating companies and industries (World Wildlife Fund, 2022-d).

In the company tools, mined scarce materials were not explicitly expressed as something in need of protection. However, Filippa K (2021) acknowledged freshwater scarcity as a risk relation connected to water consumption as a risk object. The latter was also lifted by GM (2021) and Stella McCartney (2020) in their tools.

The formative literature did not discuss scarce materials from a company perspective. A reason for this could be that the references used were not focused on technical issues, but mainly environmental and social ones. Material scarcity was rather discussed from an environmental perspective in terms of biotic depletion. Those risk relations were categorised into the nature system, linked to the object at risk *Natural resources*. This could indicate that scarce material as an object at risk could be more suitable in the nature category, which can be discussed as further improvements of the model.

During the knowledge build-up process, scarce materials was stated as something Volvo Cars intended to protect. When interviewing the internal stakeholders at Volvo Cars, a number of risk relations were raised related to the use of scarce materials in the production. Material shortage was the third most frequently mentioned links of relationship of risk overall, following emissions and carbon impact. Not getting primary material and delivery problems were also mentioned as risk relations, which could have consequences for the company's production. Inefficient material use is another risk retrieved from the interviews, that can be connected to the use of scarce materials, since that could cause further material shortage in the future. When discussing risk objects, some of the interviewees talked about global events, such as the recent covid pandemic or the ongoing Russian invasion of Ukraine. They described measurable impacts on material supply caused by events like these, one being not having any fallback material for certain components. The ability to continuously use scarce materials also depends on material access, which can be affected by the political instability in reserve and producing countries, threatening the supply of certain materials. What is also interesting is the discussions about electric vehicles (EVs) as a risk object. Some stakeholders mentioned EVs and their production processes as a technical lock-in of contemporary sustainability solutions. By only confiding in one solution for solving environmental problems, other innovations could potentially be missed. Therefore, lack of innovation threatens the use of scarce materials since a continued use increases the depletion and can result in further material shortage.

After creating the cause-effect chains, the final risk relations used for searching for indicators were *Material shortage, No fallback material, Depletion of scarce materials, Lack of innovation,* and *Freshwater scarcity*. *The Material Change* report (Drive Sustainability et al., 2018) provided two example indicators: *Virgin Material Consumption* and *Estimated rate of depletion* (Appendix XVI). It might be hard to find indicators for *Lack of innovation*, but it is an important risk to have in mind to avoid technical lock-ins when discussing sustainability solutions.

Circular and Non-Renewable Materials

Included in this category are recyclable and recycled materials, reusable materials, fossil materials, metals, virgin materials, and critical raw materials (CRM) on Level 3, which are all more specified on Level 4 (see Appendix XIII). In this report, CRM is defined according to the European Commission, i.e., raw materials important to Europe's economy because of their link to the industry, modern technology, and green technologies (European Comission, n.d.). As with scarce materials, this category is reviewed from a company perspective and the ability to keep producing products consisting of the materials in question, placing it in the technical system. Therefore, as for *Scarce materials*, the main part of risk categories was generated from the internal interviews since the literature and NGOs were more environmentally and socially oriented and did not discuss it from a perspective of material supply.

In the existing company tools, recyclability was mentioned by Apple (2019) as something that should be strived for, and recycled materials was stated by Filippa K (2021) as something to protect. Apple (2019) discussed the problem with the limited substitutability of CRM, as well as companionality of certain metals that limit the global production. According to Apple (2019), the term companionality refers to metals that are only received as a by-product when mining other materials, thus the supply of the by-product depends on the demand of the latter. What is considered the main product and by-product depends on the metals' Economic contribution (Nassar et al, 2015). The metal that contributes the most economically, will be regarded as the main product. This can cause material shortage, since the by-product, the companion metal, is financially dependent on the host metal (Nassar et al, 2015). Limited substitutability of CRM is an issue when the company lacks fallback material. The recycling rate, mentioned by Apple (2019) and GM (2021), could be a risk relation, if it is low. A low recycling rate would cause a shortage of recycled materials, an issue that was further discussed in the interviews with internal stakeholders at Volvo Cars. Furthermore, risk objects connected to material supply that were connected to *Scarce materials* could also be applied to this category, such as political instability in producing and reserve holding countries (Apple Inc., 2019).

Similarly to the NGOs, the investigated literature did not focus on *Circular and non-renewable* materials as a technical object at risk. However, risk relations raised by the organisations could be connected to the access of materials. For example, The *Material Change* report (Drive Sustainability et al., 2018) raised issues with countries with weak rule of law, corruption, and experiencing high-intensity conflict. Such circumstances have the power to influence the supply of materials and components, which has been noticeable with the current Russian invasion of Ukraine. This also relates to the EU and US dependency of imported materials (Drive Sustainability et al., 2018).

In the knowledge build-up sessions, CRM was discussed both as an object at risk and a risk object since the supply of the materials is in need of protection, while they at the same time have negative social impacts. In the interviews, the internal stakeholders mentioned both recycled and circular materials as objects at risk. Non-renewable materials as such were not stated explicitly, but deliveries of materials for production was a core issue to the interviewees. One specific risk for recycled materials that was discussed by several parties, was the quality degradation that occurs when recycling a virgin material. This implies that the degraded quality of recycled materials is a risk for de facto using the material in question. If a company wants to proceed using recycled materials in their products, the decrease in quality should be acknowledged, since it results in a trade-off between sustainability and quality. According to some interviewees, companies wanting to introduce more recycled content into their products might also get hindered by different performance and material standards or old, strict regulations. In one interview, it was mentioned that another link of relationship of risk could be the scarcity of recycled materials caused by the current societal shift towards a more circular economy. The impacts of the increased competition over sustainable components were noticeable when there was no fallback material available.

The final risk relation used to find indicators were *Reduced material performance, Material shortage, No fallback material, Depletion of non-renewable materials,* and *Lack of innovation.* The examples of indicators chosen were the same as for *Scarce materials* and are listed in Appendix XVI.

Extraction and Refining Processes

Extraction and refining processes includes four objects at risk at Level 3: mines, fossil extraction, forestry, and conversion processes. At Level 4, the materials used in those facilities are specified.The interviews were the major contributors of risk categories for this object, while the other sources did not contribute a lot. This might stem from that the interviewees were asked to talk about technical risk categories, while the other sources might not have been considering the technical system in the subject which they discussed in their texts.

No objects at risk were provided by the NGOS for this category, which is not surprising since they are not focussed on the technical system. However, the following is some risk relations, which also affect objects in the technical system, and which were mentioned. UNGC (2022-c, 2022-f) was the only NGO stating risk relations in this area, and they stated gaps in knowledge and governance, sea level rise, and legislative frameworks that are not efficient. The risk objects connected to this category were people in power (Amnesty, 2022-c), and governments and institutions (Amnesty, 2022-c; Greenpeace, 2022-j). Even though these were not mentioned in the technical sense, they can affect the technical system by causing material shortage and destruction.

The additional companies did not highlight any objects at risk either and they provided no risk relations, but Apple (2019) did provide some risk objects, for example geographic production concentration and reserve concentration. These two affect the objects at risk since they can affect the delivery of materials as well as the processes done internationally.

A couple of risk objects were stated by the literature for this category, with Drive sustainability (2018) mentioning EU dependency on imported material and US dependency on imported material. Stated risk relations connected to these was countries experiencing high-intensity conflict (Drive sustainability et al., 2018) and inadequate infrastructure (Nativa Precious Fiber, n.d.-b). These can all lead to material shortage and delivery problems.

Deliveries and long-tern supply were objects at risk added by the interviews, and they could be connected to the different types of supply stated in the model. Suggested risk relations connected to these were delivery problems, natural disasters, and material shortage. Mentioned risk objects causing these were global events and natural events. Examples of these are the recent pandemic, the current war in Ukraine, and extreme weather events such as droughts or sea level rise.

The knowledge build-up added refining concentration as a risk object. As a risk relation they mentioned rising populism, which can affect deliveries through political shifts.

The final three remaining risk relations were *Material shortage, No fallback material, Production stop*, and *Destruction*. For the latter, it was possible to find an indicator in Economic loss due to disasters, which was accessible and found on the UN website for their 17 sustainability goals (United Nations, 2022-a). Except for this indicator it was difficult to find anything on this subject.

5.1.3.3. Production Facilities

Different types of production facilities are crucial for a company's operation. It is therefore perceived as an object at risk in need of protection. The only second level object at risk in this category is *Carbon neutral and renewable energy production facilities.*

Carbon Neutral and Renewable Energy Production Facilities

The category has four objects at risk at Level 3 specifying the different types of energy production facilities – wind turbines, solar cells, nuclear power plants and hydropower plants – and they all have their own sublevels at Level 4 of specified objects at risk (see Appendix XIII). The interviews were dominant in this area probably because their answers were a motivation to include this object at risk in the first place. It is specific and might not be something that the other sources would prioritise when addressing these matters in their texts. Many of the risk relations and risk objects are the same as for *Extraction and refining processes*, but there are some additions.

For this category, WWF (2022-c) stated sea level rise as a risk relation, which can cause destruction to the facilities. It was the only risk relation the NGOs mentioned for this category, not highlighting any related objects at risk or risk objects. This probably is due to that protecting energy production facilities was not a matter mentioned in their texts.

No companies mentioned any risk categories for this object at risk, except for Apple (2019). They mentioned limited substitutability of materials as a risk relation, which is a pressing issue with sustainable energy sources, since many key raw materials used in these facilities are scarce or critical.

A couple of risk categories were provided by the literature, where the *RMO* (Drive Sustainability, n.d.) mentioned countries experiencing high-intensity conflict as a risk relation and renewable energy as an object at risk, and where *Nativa Precious Fiber* checklist (2019) stated inadequate infrastructure as a risk relation. Except for renewable energy, all the mentioned risk categories have the possibility of causing material shortage, affecting the construction and maintenance of the facilities.

Competition over sustainable materials, technical lock-in, and high costs, were some of the risk relations mentioned during the interviews. There were four risk objects which were found to cause all risk relations, and the interviews mentioned all of them: CRM, societal shifts, global events, and natural events. The objects at risk highlighted in this category were renewable energy and carbon neutral energy. Additionally, during the knowledge build-up rising populism was mentioned as a risk relation in this area, which can affect deliveries due to shifts in the politics. This is also true for CRM, which are often found in conflict areas. For risk objects such as global and natural events, there is a possibility for them to also cause destruction of facilities, in addition to material shortage.

The final risk relations in the model were *Lack of innovation*, *High costs*, *Material shortage*, and *Destruction*. Just as with *Extraction and refining processes*, the indicator that was readily available, and that was found on the website for UN's 17 sustainability goals (United Nations, 2022-a), was Economic loss due to disasters. This indicator might not be sufficient, but it was difficult to find good ones in general, probably due to the specificity of the object.

5.1.4. Identifying, Categorising, and Connecting Risk Categories

Depending on the context, it was with various difficulty that the different risk categories could be identified from the literature and conversations with the internal stakeholders. For instance, when it was implied that something needed protection, it was not always evident what was posing a threat. In areas more known by the authors, the different risk categories could be easily extracted and grouped, even though they were not mentioned explicitly. The results of the risk category grouping from literature, additional commercial companies, NGOs, knowledge build-up, and interviews, are described and listed in Appendix I-IV and VII.

The initial knowledge-build up conversations were very helpful to add categories to the list already acquired form literature, to discuss what was important to focus on and to start getting a direction of the project's progression. Valuable lessons were also learned going into the interviews.

During the interviews, some of the most frequently mentioned risk objects were *GHG's, Customer behaviour, EV's* and *mines*. Depending on the work area of the interviewees, the answers varied when asked about what was important to them to protect, as well as what was seen as a threat. Two of the more frequently mentioned objects at risk were *Profit* and *Company brand*. These two objects at risk are not included explicitly in the model, since they were deemed crucial for a company's existence. Regarding links of relationships of risk, the interviewees seemed the most concerned about *Emissions,* followed by *High costs, Not reaching sustainability goals,* and *Material* shortage.

In contrast to the interviews, none of the investigated companies used the relational theory of risk. Risk objects and links of relationships of risk were not separated in their tools, and objects at risk were not explicitly mentioned. However, the tools provided a range of impacts as well as datasets that could be used in the final model. In addition to delving into the mechanisms of the companies' material impact assessments, risk categories were extracted from each tool respectively.

As with the company tools, the NGOs did not apply the relational theory of risk. However, various risk categories in the nature system and the social system could be identified, while no technical objects at risk were highlighted. Since the NGOs do not usually raise technical issues, this was to be expected. They did however provide an unbiased perspective on the impacts company operations and activities have on humans and nature. The internal stakeholders at Volvo Cars provided the majority of technical risk categories, related to both environmental and social issues.

After the identification of risk categories, more than 400 objects at risk had been listed and were categorised into the three systems, the *Nature System,* the *Social System,* and the *Technical System.* It quickly became clear that separating the risk categories into the three systems is not always distinct. Depending on the employee's point of view, different categories could be placed into more than one system. However, by introducing the technical system, environmental and social risks that were connected to technical risk objects were included that might not have been considered if the model was limited to only nature and society. For example, facilities necessary for a company's production are human-made and therefore placed in the technical system. Nevertheless, these technical objects at risk could potentially be harmed by environmental risk objects such as extreme weather events, or global events such as war. In both cases, the risk relations are not technical, while the object at risk is.

When the number of objects at risk had been reduced in the workshop, there were 15 remaining at Level 2. An overview of these 15 objects at risk, including their systems and the level above them, is presented in Figure 9. The number of votes each object got in the second workshop exercise has been put in parentheses.

System	Level 1	Level 2
1. Nature System	1.1. Climate	1.1.1. Atmosphere (9)
		1.1.2. Ocean (7)
		1.1.3. Fresh water (8)
		1.1.4. Land + soil (9)
	1.2. Ecosystem services	1.2.1. Biodiversity (6)
		1.2.2. Natural resources (6)
2. Social System	2.1. Humans	2.1.1. Workers and discriminated groups (9)
		2.1.2. Community, Indigenous Peoples, and other discriminated groups (9)
		2.1.3. Children (7)
	2.2. Business	2.2.2. Supply chain (10)
3. Technical System	3.1. Product	3.1.1. Product quality (12)
	3.2. Materials and supplychain	3.2.2. Scarce materials (7)
		3.2.4 Circular and non-renewable materials (13)
		3.2.5. Extraction and refining processes (7)
	3.3. Production facilities	3.3.1. Carbon neutral and renewable energy production facilities (9)

Figure 9. Overview of 15 most voted for objects at risk, with the number of votes in parentheses.

One of the most time-consuming steps was linking these 15 objects at risk with risk objects, creating cause-effect chains with the links of relationships of risk. Since most risk objects can cause a number of different impacts, which in turn affect several objects at risk, the webs of cause-effect chains quickly became complicated. Additionally, one object at risk could have several impacts connected to it, but it was not always obvious which impacts could be linked to what object at risk. This indicated that, in some cases, the specification was insufficient, and gaps were identified in several spots. These had to be filled with the authors' own contributions inspired by literature, which are listed in Appendix XIV. Even if these cause-effect cascades are very complex, they will facilitate risk identification and management for Volvo Cars, providing a holistic illustration of the whole risk relationship.

5.1.5. Interactions with Internal Stakeholders

The different types of interactions with the internal stakeholders at Volvo Cars contributed to a range of results that could be interpreted in different ways. For example, the knowledge build-up sessions introduced how the people in the organisation approach these issues and provided a deeper understanding of how to communicate in similar situations, which was quite useful going into the interviews. It was also useful for the participants, since they started to think about these issues in terms that they might not have used before.

The interviews made many additions to the list of links of relationships of risk and risk objects, but they also helped the authors categorise objects at risk into the *Nature system*, the *Social system*, and the *Technical system.* There was a similarity between the mentioned objects at risk related to environmental and social issues, where *Climate* and *Human health* were common, while the technical ones varied more depending on the participants' work area. Interestingly, compared to the literature and company tools the interviews were the main provider of technical objects at risk, mentioning for example different types of materials and components as important to protect. Since the internal stakeholders naturally had a business perspective answering these questions, this seems logical. In some cases, the interviewees even preferred to discuss technical matters since they felt more confident about them than environmental and social material issues. Similarly, stakeholders working within sustainability were more confident discussing environmental and social risks. It can be concluded that the internal stakeholders had deep knowledge in their areas of expertise, not unexpectedly deeming their core issues the most important. Common for all interviewees was the business point of view, their most prioritised object at risk being the company brand and profit.

When the results from the interviews were processed in the workshop, the model went through quite many changes, mostly because of the requirement to lower the number of objects at risk at Level 2. The results from the workshop can be found in Appendix XIII. What separated this session from the interviews was that more independent reasoning was required from the participants. They expressed the difficulty they experienced with weighing the importance of each object at risk in their systems, it was challenging to decide that some were more crucial than others, and which to keep. The result of this dilemma was that many objects at risk in both the technical and the nature system were merged and moved to a different level instead of being removed, which also happened to some extent in the social system. It did not cause much trouble in all cases, but in the nature system it led to difficulties with connecting the cause-effect chain. Afterwards, it was universally agreed that the setup of the nature system was better before this change, which can be found in Appendix XII. The discussions following this conclusion regarded that if the workshop could be redone, the possibility of merging objects at risk should not be allowed, since it made it harder to assess afterwards, and that one should not listen blindly to internal stakeholders and change something that was better before.

Another problem was, to not overwhelm the participants, they were not shown Level 3 and 4 of objects at risk, making them unaware of what lower-level objects disappeared when a Level 1 or 2 was deleted. There was also a discussion regarding the three systems and the terminology surrounding the risk categories, regarding if they were too difficult to understand for it to be a beneficial way of designing the model.

However, the workshop was overall successful in lowering the number of objects at risk, which made the model more manageable for the company. It would have been much too time consuming to create cause-effect chains for more than 400 objects, whereof some might not even be seen as a priority to Volvo Cars. It will probably also be useful to have a model which includes categories which internal stakeholders have had a say in, even though there always is the problem of stakeholders caring more for the categories which are important in their own work-area.

During the case in which the model was tested, some more specific links of relationships of risk in the social and technical systems were merged into more general links of relationships, moved back in the chain, or removed all together. In the session, it was reiterated that there might have been advantages to how the model looked before the workshop. It was also mentioned that it is difficult when many stakeholders want to have their say, and that merging objects at risk in the workshop did not make the model more comprehensible. Discussions were also held regarding indicators and data, and how crucial they are for the model, while also stating that it is important to include those without indicators, since it is a demonstration that the problem is acknowledged. The case participants concluded that the model was general and not specific for any material, and that it was good that it showed the whole cause-effect chain. It was also considered to be more all-encompassing than the *RMO* from Drive Sustainability (n.d.).

5.2. The Importance of Shared Terminology

5.2.1. Facilitating Communication at Volvo Cars

This study has shown the significance of a clear terminology which is agreed upon. The mindset of common understanding has both contributed to the development of the model, as well as exposing the need for Volvo Cars to agree on collective definitions and concepts. Before the authors introduced the terminology used in by Boholm & Corvellec (2011), it was harder to distinguish what was requested when talking about risk. For example, during the knowledge build-up, the relational theory (Boholm & Corvellec, 2011) had not been fully incorporated in the methodology, and not yet introduced to the employees, which meant that all risk categories acquired from them were a mix of all three categories. This entailed a lot of work dedicated to identifying and classifying the risk categories, which was rather time-consuming. The introduction of the key concepts, i.e., object at risk, link of relationship of risk, and risk object came to be the fundamental principle of this thesis, the final model's foundation. Once accustomed to the terminology, it was concluded that this theory was the easiest way of mapping risks and their relations to what Volvo Cars perceived as important or threatening.

Confusion during the interactions with internal stakeholders could have been avoided if additional terminology had been made even more comprehensible. The first interview question, asking about objects at risk in the stakeholder's work area, was sometimes difficult for the interviewee to interpret. Even if the terminology was explained and illustrated with an example preceding the session, the answers to this question could result in what the stakeholder deemed threatening rather than what they intended to protect. The answers show that they usually focus on the risk relations and risk objects in their daily risk management. To avoid misunderstandings, the questions could have been clarified further. However, by comparing the outcome of the knowledge build-up and the interviews, there is a quite distinct difference. Since the terms object at risk, link of relationship of risk, and risk object were explained before each interview, the answers were easier to interpret than the ones from the knowledge build-up, where the concepts were not yet defined. Additionally, the second and fifth interview question, asking the stakeholder to identify social, environmental, and technical risks connected to their work area and other parts of the organisation, seemed to be easier for the interviewees to decipher. Generally, conducting interviews was a smooth way of receiving direct answers that could be immediately discussed. In some instances, it was clear that a few questions should have been specified further to be more approachable.

However, during the workshop it was still clear that this way of thinking about risk would benefit from a longer period of accustomisation, since not all participants seemed to immediately understand the difference between the three factors in the relational theory of risk. On a positive note, having been introduced to this new mindset led to contempletation among the participants, which was thought to be refreshing by several of them. One reason for this could be that the employees might not be exposed to discussions surrounding risks in their daily work.

5.2.2. Sustainability and Risk Definitions

Besides the three systems used for structuring the model and the three elements included in the relational theory (Boholm & Corvellec, 2011), sustainability and risk were two concepts that were defined in this thesis. The comparison of generated definitions from both literature and Volvo Cars' internal approach shows a similarity in the key terms of sustainability risk, even if some parts may differ. Due to the many similarities, the result for this part of the study is not emphasised in this report. Since the result for both concepts indicated that the majority of the interviewees used similar terms to describe sustainability and risk respectively, there seemed to be a shared understanding for these two terms. Therefore, the produced definitions in this thesis might not be ground-breaking. Nevertheless, they are included to acknowledge importance of defining concepts like these since they *can* be interpreted differently, which could cause confusion in a tool used for communication.

The final definition for sustainability was determined to be: "Meeting the environmental, social, and economic needs of this generation without compromising the needs of generations to come."

It was decided that the structure of the Brundtland definition (United Nations, 2022-b) should act as a foundation for the sustainability definition. Comparing that definition with the frequently used words and the statements given by the interviewees, the words *environmental, social,* and *economic* were added to the Brundtland definition, since those seem to be three key aspects of sustainability. It was also decided to replace *the present* with *this generation*, and *future generations* with *generations to come*. Key words used in interviews and their use frequency, are shown in Appendix IX. When the internal stakeholders were asked how they define sustainability and whether they consider Volvo Cars to agree with their perception, the answers were similar between the interviewees. The stakeholders' responses to defining sustainability are listed in Appendix VIII.

The Brundtland definition, together with Volvo Cars view on the concept, listed in Table 1. Volvo Cars did not explicitly state a sustainability definition on the website, but instead their ambitions for how to become a sustainable company were clearly described (Volvo Car Corporation, 2022). Additionally, Volvo has guidelines when engineering for sustainability with some key principles (Volvo Cars Corporation, 2021-a).

Table 1. Definitions of sustainability and their references.

Reference	Sustainability Definition
The UN (The Brundtland definition)	"[…] **meeting the needs** of the present **without compromising** the ability of **future generations** to meet their own needs."
Volvo Cars	*Climate Action:* "By **reducing emissions** across our entire value chain, we're aiming to become a **climate-neutral** company by 2040."
	Circular Economy: "[…] **maximising resource efficiency** across vehicles, components and materials. We're focussed on eliminating waste, making greater use of **recycled** material, and **remanufacturing** and **reusing** parts."
	Ethical and Responsible Business: "At its heart, this means doing **the right thing** – when conducting business, how we **behave as employees** and **treat our workforce**, and the expectations we place on our business partners. We want to be a force for good and have a **positive impact on society**."
	Key Principles: ➢ "Always **consider the entire life-cycle** – how are your choices affecting sourcing of material, production and use, and processes at the end of life. ➢ **Minimize weight and the materials** used for each function. ➢ **Minimize energy use** in the entire value-chain and prioritize **renewable energy.** ➢ Enable **prolonged use** of components and materials through **remanufacturing, refurbish, repair** and **reuse** (4R) and when none of the 4Rs are possible – **recycling**. ➢ **Minimize emissions and waste** in the entire life-cycle. ➢ Select materials that do **not harm the health** of people, both inside and outside the vehicle. ➢ Always consider the **social impact** of your choices."

For risk, the following definition was generated: "An event (risk object) which can have adverse impact (relationship of risk) on objects with assigned value (object at risk), and which have a certain probability of causing unintended outcomes with measurable consequences."

The final risk definition describes risk as a cause-effect-chain, where the word "objects" refers to both physical constructs and intangible concepts. The risk category concepts – risk object, object at risk, and relationship of risk – are taken from Boholm & Corvellec (2011). In the article, "the assigned value" is described as something depending on perspective and beliefs of the observer. The other chosen words were *event*, *adverse*, *impact*, *objectives*, *outcomes*, *consequences*, *probability*, *unintended*, and *value*. Key words used in the literature, interviews and the knowledge build-up, and their use frequency, are shown in Appendix XI.

Most, but not all, interviewees thought that their definitions were shared by the Volvo Cars. One of the interviewees provided two internal documents containing risk definitions, while two others explained why their definitions were not shared by the company. One of them did a lot of communication between two different departments and noticed that their risk definitions were very different, while the other did not think that their addition of risk also being a positive concept would be shared throughout the organization. The most probable reason for the varying risk definitions stems from the fact that the interviewees had a different backgrounds and work in many different areas of the organisation, which implies that they would have different outlooks on risk in their day-to-day work. Additionally, many people working in the organisation might not be aware that there are internal documents containing risk definitions, or they might just not agree with them. The risk definitions gathered from the interviews with employees at Volvo Cars are listed in Appendix X. It also provides the interviewees perception of their answers in relation to Volvo Cars view of risk.

The risk definitions identified from Boholm & Corvellec (2011) and the ISO31000 (2018) definition are listed in Table 2. Volvo Cars' view on risk is presented in Appendix X.

Table 2. Definitions of risk and their references.

Reference	Risk definition
Boholm & Corvellec	"**Risk** = **uncertainty** + **damage**"
	"[…] quantitative measures of **hazard consequences** expressed as **conditional probabilities** of experiencing **harm**'"
	"[…] the **probability** that a particular **adverse event** occurs during a stated **period of time**"
	"[…] the potential for realization of **unwanted, adverse consequences** to human life, health, property, or the environment"
	"[…] a **situation or event** where something of human **value** (including humans themselves) has been put at stake and where the outcome is **uncertain**"
	"[…] risk refers to **uncertainty** about and [the] **severity** of the **consequences** (or outcomes) of an activity with respect to something that humans **value**"
ISO31000	"***effect*** of ***uncertainty*** on ***objectives***" *Effect* = "An effect is a deviation from the expected. It can be positive, negative or both, and can address, create or result in opportunities and threats." *Objectives* = "Objectives can have different aspects and categories, and can be applied at different levels."
	"Risk is usually expressed in terms of **risk sources** […], **potential events** […], their **consequences** […] and their **likelihood** […]"

6. Conclusion and Further Improvements

This thesis has resulted in several conclusions. A conceptual model for identifying supply chain risks has been presented and tested. It includes a defined terminology that, even if it needs some time for adaption, can be regarded as comprehensive. Additionally, numerous supply chain risks have been compiled.

The results show the importance of having a shared understanding concerning concepts important to this model, such as risk and sustainability. During this study, it has become evident that there is a need of a conceptual model with definitions universal to Volvo Cars, to ease the communication between employees. This gives even more susbtance to the need of creating a conceptual model that all internal stakeholders can absorb and understand, avoiding future misunderstandings.

When comparing the model produced in this thesis with the examples of tools provided from the commercial companies and the *Material Change* report (Drive Sustainability et al., 2018), it can be concluded that this model provides a complementary perspective on risk. By using Boholm and Corvellec's (2011) relational theory, the model became more comprehensive than the ones used for comparison. The implementation also allows for a more precise distinction between possible causes and effects. In the case where the model was tested, it was concluded that if one follows the cause-effect chains in the model, the cause of the risks can be found quite easily. It was also concluded that since there is some type of indicator for each object at risk in the model, there is substance for continued development.

Drawbacks with this model could be that it is *too* extensive, and potentially includes risk objects that are out of Volvo Cars' control. Even if requirements for procurement can be an effective way to enhance Volvo Cars' ability to control the environmental and social impacts of its supply chain, global events such as a pandemic or natural disaster are out of the company's control. However, keeping them in the model shows awarness and acknowledgement of issues as such. Another drawback would be that the model is not yet applicable to its intended purpose, which is why the authors suggest further improvements of the model to Volvo Cars.

The next steps for Volvo Cars will be to use this thesis as a foundation for developing an approachable tool adapted to their purpose. Primarily, it should be evaluated once more whether the resulting 15 objects at risk are the ones Volvo Cars intend to prioritise. After the workshop it was concluded that the participants were not fully aware of the consequences of removing certain objects at risk. The model was also complicated by the merging of objects they were unwilling to remove, since this lowered the specificity of each object, making indicators more difficult, or even impossible, to find. The idea of the model is to facilitate the identification of risks prioritised to Volvo Cars. Merging categories instead of selecting the most important ones makes it rather more difficult to assess and manage risks, which could be a limitation for the model's feasibility. Thus, the arrangement of the model preceding the workshop could be re-examined, refraining from combining different categories.

Another question that emerged from the workshop, was whether the division into the three systems, the *Nature system*, the *Social system*, and the *Technical system*, rather confuses the users than simplifying the structure of the model. For example, it seemed confusing to the internal stakeholders that the systems only regarded objects at risk and not all risk categories. The intention was to let the three system guide the user in identifying risks. However, if the definition of the systems is deemed too complicated to comprehend, a division based on other attributes could be considered to make the tool more user-friendly.

If there is a wish to extend the model to more than 15 objects at risk, it should be considered to apply a system which can help the user prioritise between different issues, either by quantification or a weighting system, for example. A model with a long list of categories could otherwise seem overwhelming, impeding the risk management process. With a system like this, there would be a hierarchy indicating which issue to deal with first, before engaging in matters less important to the company. The order of prioritisation could be different depending on which department uses the model, and what risks they deem more important to their work. Inspiration can be taken from the scoring system used in Apple's (2019) materiality impact profile.

Finally, the list of indicators should be supplemented with additional ones since this thesis only provides examples of some indicators from a limited number of references. To fully utilise the model, the indicators need to be specified even further and datasets must be mapped for each selected indicator. Additionally, the cause-effect chains can be extended to more than three risk relations by mapping additional risk categories not mentioned in this model.

Thus, the model is not operational at its current state. Besides the further improvements mentioned above, it must be established how it can be connected to Volvo Cars' materials. By mapping which objects at risk are relevant for each material, the indicators can be used to identify risk relations connected to them, enabling targeted risk management.

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Appendix I – Risk Categories from the Literature

Risk categories retrieved from literature studies:

1. Baumann & Tillman (2004)
2. OECD (2022)
3. Goedkoop, et al., Product Social Impact Assessment Handbook – 2020 (2020-a)
4. Volvo Cars (2021)
5. Goedkoop, et al., Methodology Report Product Social Impact Assessment - 2020 (2020-b)
6. Drive Sustainability et al. (2018)
7. Nativa Precious Fiber (2019)
8. Hofmann et al. (2013)

The ones marked in yellow are included in the model but in different wording or were deemed irrelevant in the model after the workshop.

Objects at Risk

Reference / Objects at Risk	1	2	3	4	5	6	7	8	SUM
Groundwater						1			1
Legality protected areas						1			1
Threatened species						1			1
Biodiversity	1					1	1		3
Ecosystem services						1			1
International recognised areas						1			1
Animal welfare							1		1
Liberty							1		1
Freedom of speech							1		1
Adequate standards of living							1		1
Renewable energy						1			1
Transparency and traceability in supply chain				1					1
Community health and safety						1			1
Livelihood						1			1
Cultural heritage	1					1			2
Material and immaterial resources			1						1
Historical liabilities						1			1
Institutional capacity						1			1
Local workforce						1			1
Local procurement						1			1
Legal compliance						1			1
Payment of taxes and EITI						1			1
Social license to operate						1			1
Soil fertility							1		1
Forage resources							1		1
Water quality							1		1
Accomodation						1			1
Electricity						1			1
Basic supplies						1			1
Basal facilities					1				1
Workforce facilities					1				1
Work-life balance			1						1
Job satisfaction					1				1

Access to water						1			1
Privacy							1		1
Clean areas for food storage, eating, and resting							1		1
Human health	1								1

Links of Relationship of Risk

Reference / Links of relationship of risk	1	2	3	4	5	6	7	8	SUM
Suffer water pass by flows						1			1
Retrenchment						1			1
Non-payment of dues		1							1
Child deprived education						1			1
Child labour			1			1			2
Habitat alterations and impact on biodiversity	1								1
Abiotic depletion	1								1
Biotic depletion	1								1
Eutrophication	1								1
Deforestation						1			1
Conflict with agriculture						1	1		2
Conflict with livelihoods						1			1
Forced labour			1			1			2
Overlap with areas of conservation importance						1			1
Discrimination and lack of diversity			1			1			2
Disciplinary practices and violence						1			1
Abuses by security contractors		1							1
Mining in conflict affected areas						1			1
Support of armed groups		1							1
Depletion of stratospheric ozone	1								1
Acidification	1								1
Photo-oxidant formation	1								1
Global warming	1								1
Dust and other air emissions						1			1
Greenhouse gas emissions						1			1
Hazardous waste							1		1
Overburden, tailings, effluents						1			1
Soil contamination						1			1
Water contamination						1			1
Boycott								1	1
Acid mine drainage						1			1
Potential for acid discharge to the environment						1			1
Resettlement and displacement						1			1
Conflict with communities						1			1
Incidences of conflict with Indigenous people						1			1
Extortion						1			1
Bribery and facilitation						1			1
Money laundering		1							1
Bribery and fraud		1							1
Toxicological impact on human health (excluding work environment)	1								1
Non-toxicological impacts on human health	1								1
Ecotoxicological impacts	1								1

Soil erosion							1		1
Soil compaction							1		1
Loss of soil organic matter							1		1
Land degradation due to overgrazing							1		1
Disposal of hazardous waste and materials on grazing land							1		1
Excessive use of fertilizers and pesticides							1		1
Damage of beneficial organisms due to pesticide use							1		1
Potential for harm from hazardous materials and chemicals							1		1
Preconditions for radioactive materials in ores and tailings							1		1
Invasive species in farming							1		1
Grazing on high consevation value areas							1		1
Grazing on areas with endangered wild life species							1		1
Degradation of forage resources							1		1
Zoonotic illnesses and diseases							1		1
Injuries							1		1
Productive disorders							1		1
Inappropriate practices							1		1
Insufficient space to move about							1		1
Long term close confinement or tethering							1		1
Late treatment of diseases, illnesses, or injuries							1		1
Inhumane euthanisia							1		1
Animal suffering							1		1
Insufficient nutrition, care, handling and veterinary attention							1		1
Insufficient hygiene practices							1		1
Excessive number of animals in the transport							1		1
Unhygienic and unsafe transport conditions							1		1
Malnutrition							1		1
Dehydration							1		1
Countries with weak rule of law						1			1
Corruption						1			1
Countries experiencing high-intensity conflict						1			1
Contaminated feed							1		1
Food and water deprivation							1		1
Deprivation of natural light							1		1
Insufficient breeding conditions							1		1
Isolation of herd animal individuals							1		1
Not using pain relief (castration)							1		1
Unsanitary conditions (Castration)							1		1
Hot branding and horn branding							1		1
Use of inappropriate tools							1		1
Untrained workers performing critical tasks							1		1
Not euthanizing seriously ill or injured animals							1		1
Slaughter method inducing stress and pain							1		1
Inadequate infrastructure							1		1
Discomfortable and unsanitary housing conditions							1		1
(Negative) human health impacts in work environment	1								1
Nuisances					1				1
Harassments					1				1
Lack of emergency procedures							1		1

Risk Objects

Risk object \ Reference	1	2	3	4	5	6	7	8	SUM
Estimated rate of depletion						1			1
Virgin material consumption						1			1
Renewable energy						1			1
Noise and vibrations	1					1			2
Residual end of life waste						1			1
Historical liabilities						1			1
Storage of fuel, oils, fertilizers, and pesticides							1		1
EU dependency on imported material						1			1
US dependency on imported material						1			1
Non-state armed groups		1							1
Workplace hazards and machinery						1			1
Hazardous substances						1			1
Artisanal and small-scale mining						1			1
Rates of injury and fatalities	1				1				2
Distance to workplace					1				1
Groundwater use						1			1

Appendix II – Risk Categories from Additional Company Tools

Risk categories retrieved from additional commercial companies:

1. Apple (2019)
2. Nike (2012)
3. Filippa K (2021)
4. GM (2021)
5. Stella McCartney (2021)

The ones marked in yellow are included in the model but in different wording or were irrelevant in the model after the workshop.

Objects at Risk

Company / Objects at Risk	1	2	3	4	5	SUM
Recyclability	1					1
Workers					1	1
Livelihoods				1	1	2
Supply chain					1	1
Migrant workers					1	1
Women					1	1
Human health					1	1
Human well-being					1	1
Tropical forests				1		1
Local communities				1		1
Biodiversity			1	1		2
Fair working conditions			1			1
Right to free association			1			1
Whistleblower			1			1
Recycled materials			1			1
Biomaterials			1			1

Links of Relationships of Risk

Company / Links of Relationship of risk	1	2	3	4	5	SUM
Geochemical impacts	1					1
Hazardous waste		1				1
Carcinogenicity		1				1
Acute toxicity		1				1
Chronic toxicity		1				1
Reproductive toxicity and endocrine disruption		1				1
Corruption and conflict	1		1			2
Limited global production (companionality)	1					1
Limited substitutability (CRM)	1					1
Air emissions					1	1

Water pollution			1		1	2
Modern slavery					1	1
Discrimination			1		1	2
Freshwater scarcity			1		1	2
Biodiversity loss					1	1
Deforestation					1	1
Global warming					1	1
GHG emissions			1	1		2
Water toxicity			1			1
Hazardous chemcials			1			1
Microplastics			1			1
Too long working hours			1			1
Not getting paid living wage			1			1
Harassments			1			1
Child labour			1			1
Forced labour			1			1

Risk Objects

Company / **Risk object**	**1**	**2**	**3**	**4**	**5**	**SUM**
Land use (intensity)		1	1		1	3
Chemical usage	1					1
Energy intensity		1				1
Recycling rate	1			1		2
Municipal solid waste		1				1
Industrial waste		1				1
Compostable waste		1		1		2
Mineral waste		1				1
Political stability in producing countries	1					1
Political stability in reserve holding countries	1					1
Geographic production concentration	1					1
Reserve concentration	1					1
Companionality	1					1
Waste				1	1	2
Greenhouse gases					1	1
Water consumption			1	1	1	3
Total energy consumption			1	1		2
End-of-life treatment				1		1
Landfill				1		1

Appendix III – Risk categories from NGOs

Risk categories retrieved from NGOs:

1. Amnesty (2022-a-b-c-d-e-f-g)
2. Human Rights Watch (2022-a-b-c-d-e-f)
3. Greenpeace (2022-a-b-c-d-e-f-g-h-i-j-k)
4. WWF (2022-a-b-c-d-e-f-g-h)
5. UNGC (2022-a-b-c-d-e-f-g)

The ones marked in yellow are included in the model but in different wording or were irrelevant in the model after the workshop.

Objects at Risk

Objects at Risk / **NGO**	**1**	**2**	**3**	**4**	**5**	**SUM**
Local People	1	1	1	1	1	5
Local peoples' livelihood	1				1	2
Community air quality	1			1		2
Community water quality	1	1			1	3
Community land quality		1				1
Economy of families		1				1
Indigenous Peoples	1		1	1		3
Indigenous Peoples' livelihood	1				1	2
Air quality on Indigenous land	1			1		2
Water quality on Indigenous land	1				1	2
Cultural Heritage	1					1
Children	1	1			1	3
Childrens education		1				1
Discriminated groups	1					1
Individuals	1					1
LGBT-people		1				1
Women and Girls		1				1
Women and girls' livelihood		1			1	2
Women and girls' education		1				1
Freedom of expression	1					1
Biodiversity			1	1	1	3
Health		1	1	1	1	4
Food security			1	1	1	3
Human security			1	1	1	3
Econmic growth					1	1
Water			1	1	1	3
Water quantity					1	1
Water supply					1	1
Workers			1		1	2

Flora			1	1	1	3
Fauna			1	1	1	3
Company brand					1	1
Climate			1	1		2
Communities			1	1		2
Farm animals			1			1
Ecosystems			1	1		2
Human populations of the Global South					1	1
Coastal residents				1		1
Freshwater				1		1
Freshwater habitats				1		1
The water cycle				1		1
Wildlife				1		1
Wild places				1		1

Links of Relationships of Risk

NGO / Links of Relationship of risk	1	2	3	4	5	SUM
Land grabbing	1					1
Forced labour	1	1			1	3
Contamination	1	1				2
Corruption	1	1				2
Lacking capacity of preserving human rights	1					1
Dependence on company investments	1					1
Withholding information	1					1
Child labour	1	1			1	3
Discrimination	1	1				2
Silencing people	1					1
Oppression	1					1
Abuse		1				1
Relocation		1			1	2
Deprivation of education		1				1
Health issues		1			1	2
Inequality		1				1
Child marriage		1				1
Sex trafficking		1				1
Climate change		1	1		1	3
Gaps in knowledge and governance					1	1
Legislative frameworks that are not efficient					1	1
Insufficient wages					1	1
Industrial wastewater runoff					1	1
Pollution (air, animal waste, plastic, river)			1	1	1	3
Global warming				1	1	2
Overfishing			1	1		2
Inhumane treatment of animals			1			1
Unfair working conditions			1			1

Overconsumption			1			1
Climate change induced forest fires			1	1		2
Deforestation			1	1		2
Unsustainable production			1			1
Acidification				1		1
Eutrophication				1		1
Malnourishment				1		1
Topsoil loss				1		1
Freshwater depletion				1		1
Ocean acidification				1		1
Sea level rise				1		1
Freshwater species decline				1		1
Species loss				1		1
Species extinction				1		1
Ecosystem disruption				1		1
Cultural value loss				1		1
Forest degradation				1		1
Diminishing agricultural yields				1		1
Greenhouse gas emissions				1		1

Risk Objects

NGO / **Risk object**	**1**	**2**	**3**	**4**	**5**	**SUM**
Need for labour	1	1			1	3
Need for investments	1					1
Domestic regulation	1					1
Need for mining scarce materials	1					1
Poverty	1	1			1	3
Prejudice	1	1				2
Governments and institutions	1		1			2
People in power	1					1
Exploiting/operating companies/industries	1	1	1	1	1	5
Increasing need of natural resources	1	1				2
Employer		1			1	2
GHG's				1	1	2
The current energy system			1	1		2
Consumers			1			1
Waste handling systems			1			1
The current food production system			1	1		2
Freshwater use				1		1
The current infrastructure system				1		1
Human population growth				1		1
Population of the global south					1	1

Appendix IV – Risk Categories from Knowledge Build-up and Workshop

Risk categories retrieved from the knowledge build-up and workshop:

1. Knowledge build-up
2. Workshop

The ones marked in yellow are included in the model but in different wording or were irrelevant in the model after the workshop.

Objects at Risk

Object at risk \ Sessions	1	2	SUM
Scarce materials	1		1
Waste export restrictions	1		1
Air quality	1		1
Access to water	1		1
Water quality	1		1
Soil quality	1		1
Migrant workers	1		1
Access to education (Education)	1		1
Tax payments	1		1
Whistleblower	1		1
Animal rights	1		1
Freedom from hunger and thirst	1		1
Freedom from discomfort	1		1
Freedom from pain, injury and disease	1		1
Freedom to express normal behavior	1		1
Freedom from fear and distress	1		1
Biodiversity (terrestrial AND aquatic)	1		1
CRM	1		1
Carbon neutral energy	1		1
Data accuracy	1		1
Quality	1		1
Material properties		1	1

Links of Relationships of Risk

Links of Relationship of risk \ Session	1	2	SUM
Soil quality deterioration	1		1
Micro plastic generation	1		1
Supplying countries' export restrictions (China export restrictions)	1		1
Land grabbing	1		1
Recruitment fees	1		1
Worst forms of child labor	1		1
Illicit work without residence permit	1		1
Ocean Acidification	1		1
Water degradation	1		1

Sustainability hypocrisy	1		1
Devaluation	1		1
Biodegradation	1		1
Particle lung deposition	1		1
Leakage of vehicles	1		1
Rising populism	1		1
Underemployment	1		1
Duplication of work	1		1
Illicit trade	1		1
Illicit movement of Volvos vehicles	1		1
Bad associations/bad PR (Volvo cars used for drug trade, used by dictators etc)	1		1
Job insecurity	1		1
Conflicts with agriculture	1		1

Risk Objects

Session / Risk object	1	2	SUM
Refining concentration	1		1
Noise	1		1
Whistleblower	1		1
Workplace temperature	1		1
Water consumption	1		1
Water temperature	1		1
CRM	1		1
Total resource consumption	1		1
High impact materials	1		1
Carbon neutral energy	1		1
Renewable energy end-of-life (e.g. circulation of wind turbines etc)	1		1
Energy used in recycling	1		1
Particle Matter	1		1
Legacy chemicals	1		1
Competence shift	1		1
Speed of change	1		1
Hazardous substances used in the recycling process	1		1

Appendix V – Interview Questions

1. Interview Questionnaire - English Version

Introduction:
Introducing ourselves and the subject.

Opening questions:

- Is it okay for you that we record the meeting? You will be anonymous in the report.
- For how long have you been working at Volvo?
- Can you tell us about your role at the company and your working tasks?

General questions about risks:

5. What is the object at risk/endpoint in your working area?
    a. If this includes goals or objectives, where are those defined?
    b. How much of this is internal and how much is external?

6. What risks do you see connected to your work area/tasks?
    a. Are there any internal/external social risks?
    b. Internal/external technical?
    c. Internal/external environmental?

7. How do you assess risks?

8. Do you use a support tool for risk management?
    a. If yes, what tool(s) do you use?
    b. If yes, how well do you think these tools work? How could these tools be improved? In what way do you think that they are good?
    c. If no, do you think you could benefit from a support tool for managing risks? What would such a tool need to look like?

9. Can you identify some other objects at risk in other parts of the organisation?
    a. What risks are connected to those objects at risk?

10. How would you define risk?
    a. Would you consider this to be a shared definition of risk within this function?

11. Can you name a few examples of risk thinking or risk management in your daily work?
12. How do you categorise, classify, or group risks?

Sustainability risk questions (if time allows):

13. How would you define sustainability?
    a. Would you consider this to be a shared definition of sustainability within this function?
    b. What is your understanding of what sustainability risks are?

14. Do you treat sustainability risks as a separate risk category or integrate a sustainability perspective into other risk categories? Why?

15. What potential barriers do you see to including a sustainability perspective in risk management?

16. What could be success factors for integrating a sustainability perspective?

Finishing question:

17. Is there anything else you would like to add?

2. Interview Questionnaire - Swedish Version

Introduktion:
Introducera oss själva och ämnet.

Inledande frågor:

- Är det ok att vi spelar in mötet? Du/ni kommer vara anonym/a i arbetet.
- Hur länge har du/ni jobbat på Volvo?
- Kan du/ni berätta om din/era roll(er) på företaget och dina/era arbetsuppgifter?

Frågor om generella risker:

1. Vad är skyddsobjektet inom ditt/ert arbetsområde?
    a. Om detta inkluderar mål eller riktlinjer, var är dessa definierade?
    b. Hur mycket av detta är internt och hur mycket är externt?

2. Vilka risker kan du/ni se som är kopplade till ditt/era arbetsområde(n)?
    a. Finns det några interna/externa sociala risker?
    b. Interna/externa tekniska risker?
    c. Interna/externa miljörisker?

3. Hur bedömer du/ni risker?

4. Använder du/ni ett verktyg för risk management?
    a. Om ja, vilket/vilka verktyg?
    b. Om ja, hur bra tycker du/ni att dessa verktyg fungerar? Hur kan de förbättras? På vilket sätt tycker du/ni att dom är bra?
    c. Om nej, tror du/ni att ni skulle gynnas av ett verktyg för risk management, och hur skulle ett sådant verktyg kunna se ut?

5. Kan du/ni identifiera några andra skyddsobjekt i andra delar av organisationen?
    a. Vilka risker är kopplade till dessa skyddsobjekt?

6. Hur skulle du/ni definiera risk?
    a. Anser du/ni att det är en vedertagen definition inom organisationen?

7. Kan du/ni ge exempel på hur man tänker på och behandlar risker i ditt/ert dagliga arbete?

8. Hur kategoriserar, klassificerar, eller grupperar ni risker?

Frågor om hållbarhetsrisker (om tiden tillåter):

9. Hur skulle du/ni definiera hållbarhet?
    a. Anser du/ni att det finns en delad definition av hållbarhet inom organisationen?
    b. Vad uppfattar du som hållbarhetsrisker?

10. Behandlar ni hållbarhetsrisker som en separat riskkategori eller integrerar ni hållbarhetsperspektiv i andra riskkategorier.? Varför?

11. Vilka potentiella barriärer kan du/ni se för att inkludera ett hållbarhetsperspektiv i risk management?

12. Vad skulle kunna vara bra för att integrera ett hållbarhetsperspektiv?

Avslutande fråga:

13. Är det något mer du/ni vill tillägga?

Appendix VI – Internal Stakeholder Participants

The table below lists the participants from the knowledge build-up, interviews, and workshop, as well as their work area. The session(s) they participated in is/are marked with an X.

Work Area	Codename	Specified Work Area	Knowledge build-up	Interviews	Workshop
Vehicle Propulsion	AA	Battery Concept & Industrialization		X	
	AB	Strategy			X
Vehicle Platform	BA	Body Technology		X	X
Vehicle Tophat	CA	Solution & Architect Team		X	
	CB	Solution & Architect Team			X
Sustainability & Volvo Cars Strategy	DA	Sustainability & Volvo Cars Strategy		X	
	DB	Sustainability & Volvo Cars Strategy		X	
	DC	Sustainability & Volvo Cars Strategy		X	
	DD	Sustainability & Volvo Cars Strategy	X		
Software & Electronics Platform	EA	Product and Systems		X	
Design	FA	Colour & Material		X	
	FB	Strategic & Brand Design		X	
	FC	Colour & Material		X	
	FD	Design Development Colour & Material		X	X
Global Procurement	GA	Global Procurement Sustainability		X	
	GB	Wheel Suspension and Steering		X	
	GC	Wheel Suspension and Steering		X	

	GD	Procurement Propulsion & Sustainability		X	
	GE	Global Procurement Sustainability	X		
	GF	Global Procurement Sustainability	X		
Complete Vehicle Engineering	HA	Vehicle Architect Material Efficiency		X	
	HB	Sustainability Architecture		X	
	HC	Sustainability Architecture	X		X
	HD	Environmental Attribute & Material	X		X
	HE	Environmental Attribute & Material	X		X
	HF	Environmental Attribute & Material	X		X
	HG	Sustainability Architecture			X
	HH	Environmental Attribute & Material			X
	HI	Environmental Attribute & Material	X		X
	HJ	Environmental Attribute & Material	X		X
	HK	Environmental Attribute & Material			X
	HL	Environmental Attribute & Material	X		
	HM	Environmental Attribute & Material	X		
	HN	Environmental Attribute & Material	X		
Environmental Protection Global	IA	Environmental Protection Global			X

Appendix VII – Risk Categories from Interviews

Risk categories retrieved from the interviews:

1. Vehicle Propulsion
2. Vehicle Platform
3. Vehicle Tophat
4. Sustainability & Volvo Cars Strategy
5. Software & Electronics Platform
6. Design
7. Global Procurement
8. Complete Vehicle Engineering

The ones marked in yellow are included in the model but in different wording or were irrelevant in the model after the workshop, and the ones in blue were non included since they stand above the others in terms of how crucial they are for a company.

Objects at Risk

Work Area	**1**	**2**	**3**	**4**			**5**	**6**				**7**				**8**		
Objects at Risk \ Interviewee	AA	BA	CA	DA	DB	DC	EA	FA	FB	FC	FD	GA	GB	GC	GD	HA	HB	**SUM**
Climate	1				1	1				1	1				1	1	1	8
EV energy efficiency	1																	1
Battery	1																	1
Battery lifetime	1																	1
Production		1	1	1	1	1				1		1	1	1				9
Supply chain		1	1	1														3
Company goals				1	1	1							1	1	1			6
Biodiversity				1	1	1		1	1							1		6
Water				1				1	1									3
Company Brand		1	1	1				1	1	1		1						7
Community health					1	1												2
Planet				1	1	1												3
Human health and well-being	1			1	1	1	1	1	1	1	1	1					1	11
Profit		1	1	1	1	1	1					1	1	1			1	10
Product													1	1				2
Steel													1	1				2
The environment				1						1	1		1	1			1	6
Nature																1		1
Customer				1			1	1	1							1	1	6
Agricultural land		1	1															2
Components		1	1															2
Forest				1												1		2
Workers				1			1						1	1		1	1	6
Sensitive information				1														1
Local suppliers	1							1	1									3
Transparency												1						1
Competence					1	1												2
Sales		1	1	1						1	1	1	1	1				8
Deliveries				1											1			2
Manufacturing				1								1						2
Low emission materials		1	1		1	1												4

Recycling	1																1
Renewable energy	1			1													2
Human rights				1				1		1	1						4
Product quality							1						1	1	1		4
Climate neutral energy												1					1
Knowledge		1	1				1			1	1						5
Recycled materials		1	1												1		1	4
Long-term supply		1	1														2
Investments					1	1											2
Tropical rainforest																1		1
Creativity										1	1						2
Cooperation										1	1						2
Communication										1	1						2
Flora	1			1													2
Fauna	1			1													2
Experience		1	1														2
Storage													1	1			2
Natural resources	1																1
Circular material										1	1						2
Continous Improvement				1						1	1						3

Links of Relationships of Risk

Interviewee / Links of Relationships of Risk	AA	BA	CA	DA	DB	DC	EA	FA	FB	FC	FD	GA	GB	GC	GD	HA	HB	**SUM**
High energy use (operations, recycling)	1						1									1		3
Tearing	1																	1
Material shortage (high demand of green materials, components)		1	1		1	1				1	1		1	1				8
Global warming/Climate change (fossil energy)	1			1											1			3
Unethical extraction							1											1
Bad working conditions	1				1	1	1								1			5
High water use							1											1
Disease							1											1
Chemical output								1	1									2
Adverse media				1								1						2
Carbon impact					1	1												2
Not reaching sustainability goals (financial impact, reputation, customer relation, stakeholder relation, legal requirements)	1	1	1	1	1	1						1	1	1				9
Toxicity (human toxicity, ecotoxicity)										1	1						1	3
Child labour		1	1				1	1	1									5
Untraced supplychain		1	1									1						3
Conflict with agriculture		1	1							1	1					1		5
Suppliers not living up to standards (components, material quality, sustainability goals)		1	1												1			3

Delivery problems (untimely deliveries, uncapability to keep up with production speed, out to customer)		1	1				1					1			1			5
Scarcity of recycled materials		1	1															2
Not getting primary material		1	1															2
Dependency on CRM		1	1															2
No fallback material		1	1															2
Not living up to performance or material standards (legal requirements, UX)		1	1		1	1									1	1		6
Rigidity in the processes								1	1	1	1							4
Dishonest trace reporting												1						1
Improper waste handling										1	1					1		3
Deforestation										1	1				1	1		4
Decreasing biodiversity																1		1
Lack of material knowledge										1	1							2
Technical lock-in					1	1				1	1				1	1		6
Miscalculation during design		1	1															2
Production error		1	1															2
Development prevention (of local suppliers)								1	1									2
Unwillingness to take risk (for continous improvement)								1	1									2
Too high risk-appetite								1	1									2
Suppliers' lack of knowlege												1						1
Bankruptcy				1	1	1												3
Increased complexity in processes (new materials)										1	1							2
Designing for appearance instead of sustainability										1	1							2
Penalties		1	1	1														3
Decreased sales (ugly product, delivery problems, not living up to requirements)				1	1	1		1	1				1	1				7
Customer dissatisfaction				1												1		2
Production stop				1	1	1						1	1	1				6
Lack of validation (supply chain, assembly line)		1	1									1						3
Not prioritising sustainability												1						1
High costs (New green technology, must be able to sell the product, short-term cost-saving)		1	1	1	1	1	1					1	1	1				9
Lack of sustainability solutions					1	1							1	1				4
No access to green energy													1	1	1			3
Competition over sustainable components													1	1				2
Stress (customer, worker, hard deadlines)										1	1	1					1	4
Modern slavery				1	1	1												3

Human rights violation				1														1
Competent people choosing other companies (more sustainable ones)					1	1												2
Destruction of living area (Operations for CO2-neutrality)															1			1
Untested components entering production							1											1
Reparation cost							1											1
Quality degradation (recycling)													1	1	1	1		4
Not keeping up with societal shifts (other companies take the lead)								1	1	1	1		1	1				6
Substitute substances deteriorate material properties																	1	1
Emissions (Operations, transportations, production of CO2-neutral tech)	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	15
Inefficient material use													1	1	1			3
Global crisis (War, pandemic)															1			1
Small selection of suppliers (High standards)													1	1				2
Lack of cooperation (within company)										1	1							2
Dependency on suppliers		1	1												1			3
Accidents (work related)							1											1
Lack of communication (within company, different definitions of risk/sustainability, directions regarding evaluating suppliers)		1	1	1						1	1					1	1	7
Surplus of more common materials (due to rare material shortage)													1	1				2
Natural disasters				1														1
Improper end-of-life treatment (discard before end of life, not dismantling product for reuse of parts)	1									1	1							3
Narrow sustainability focus (Too much focus on CO2, not so much on ethical aspekts and circular economy)					1	1							1	1			1	5
Misinformation																1		1
No universal solutions (some global solutions do not work everywhere)										1	1							2
Tradeoff (sustainability - safety/quality)										1	1		1	1				4
Overconsumption										1	1							2
Not taking responsibility (for climate)					1	1												2
Lack of / improper management tools				1														1

Risk Objects

Work Area	1	2	3	4			5	6				7				8		
Interviewee / Risk object	AA	BA	CA	DA	DB	DC	EA	FA	FB	FC	FD	GA	GB	GC	GD	HA	HB	SUM
Product properties (weight)	1																	1
EV (battery, fast charging, lithium, cobalt)	1			1	1	1	1			1	1	1						8
International suppliers	1			1									1	1	1			5
Global events (leading to e.g. pandemic)		1	1	1											1			4
Refining capacity (local, international)		1	1															2
Emissions reductions (in important operation regions affecting production)		1	1															2
CRM		1	1		1	1												4
Customer (behavior, preference)				1				1	1	1	1				1	1	1	8
Legislation				1	1	1				1	1	1						6
Natural events (weather events, land slide, earh quake)				1														1
Mines				1	1	1	1			1	1		1	1				8
Water use							1									1		2
Energy use							1	1	1									3
Process chemicals							1	1	1	1	1							5
Product materials and chemicals				1				1	1	1	1						1	6
GHG's	1	1	1	1			1			1	1	1	1	1	1	1	1	13
Sustainability goals (Company, suppliers)					1	1		1	1	1	1				1			7
Fossil materials								1	1							1		3
Product use										1	1							2
New materials										1	1							2
Tradition								1	1	1	1				1			5
Biomaterials		1	1							1	1					1		5
Transportation (emissions, costs)		1	1				1											3
(scarcity, chemicals, quality)	1	1	1														1	4
Performance and material standards		1	1					1	1	1	1							6
Regulation (old, strict)				1				1	1			1						4
Sensitive information				1														1
Long supply chain							1											1
Requirements for global reach								1	1									2
Being costs driven (no other interest)								1	1			1						3
Risk appetite								1	1									2
Supplier data	1																	1
Societal shift (green solutions, high demand)		1	1	1	1	1	1	1	1	1	1		1	1				12
High production speed												1						1

Cutting edge in sustainability (fast development, high costs, not the best technology)					1	1						1					1	4
Material access (raw material, components)					1	1									1			3
Product UX (sustainable materials but ugly)								1	1							1	1	4
Renewable energy (access, production of parts)	1			1	1	1				1	1				1			7
WEEE										1	1							2
Holistic approach (too wide focus)								1	1									2
Consensus (long time to find the perfect solution)								1	1									2
Banning substances																	1	1
Fossil energy										1	1	1						3
Communication with competitors (before something is finished)																	1	1
High demands on suppliers (sustainability, quality, human treatment)													1	1				2
Company hierarchy										1	1							2
Landfill															1			1
hard to recycle, hard to dismantle)	1																	1
Use of animal	1																	1
Green funds		1	1															2
Time plans and deadlines										1	1							2
cooperation, communication)										1	1							2
Cost-savings (short-term)										1	1							2
Production (producing is not sustainable)															1			1
Global production (might not have global solutions)										1	1							2
Voluntary reporting												1						1

Appendix VIII – Sustainability Definitions from Interviews

This table shows the answers to interview question 9 and 9a in Appendix V. A list of the participants and their work area are listed in Appendix VI. The participants with a (*) behind their initials have had their answer translated from Swedish to English. *X* indicates that the interviewee was not present when this question was asked.

Work area	Interviewee	Definition	Shared by Volvo?
Vehicle Propulsion	**AA***	I would like to rely on what our company says in our strategy [...] the three pillars: Climate - We are going to be climate neutral. Circularity - To use the Earth's resources in a good way. To reuse as much as possible, give things a long life. This is also connected to the climate issue, because if we do the circularity in a good way, we minimise the fossil emissions at the same time as vi minimize the social, health-related, and environmental risks. Ethical manufacturing, production, and use - We operate in a society, and we are a good force that you can trust. You can trust that all our employees and sub-suppliers have reasonable and fair working conditions. That we minimise our impact on Earth, emissions of substances harmful to the environment.	Yes.
Vehicle Platform	**BA**	"[...] the standard answer, of course, is that we see it as three pillars. Climate action, circular economy, and ethical and responsible business, and we frame it in that way. [...] Understanding the usage of the vehicle and the architecture that comes with that, and the materials will need what the material palette looks like. How that connects to the four R's and end of life." "And all of it, of course, sustainability means good business, at its heart. We're doing this because, we're good people, but we're also doing this because we like to make money and sell cars, so there is a sustainable economics part of this as well, that should never be forgotten."	The three pillars - Yes. Concept definition - No.
Vehicle Tophat	**CA**	[Agreeing with BA] "[...] and as [BA] mentioned, how to design the components to be able to make something useful in the end and not only burn it up basically"	The three pillars - Yes. Concept definition - No.

Sustainability & Volvo Cars Strategy	**DA***	The way we work it is strategic risks, since it is our long-term business strategy. However, some of the risks can fall into short-term risks [...]. Regarding social risks or risks related to human rights, it is more like "compliance" according to the new model.	Yes.
	DB*	A clear understanding of your total environmental impact in your organization, and your will and ability to work to improve it.	Not in those exact words, but in general terms.
	DC*	X	X
Software & Electronics Platform	**EA***	From a company perspective it is the three pillars. It is circularity, [...] renewable materials, and ethical and moral aspects [...].	Yes.
Design	**FA***	We talk a lot about social sustainability. [...] I think that design is one kind of sustainability. [...] It is sustainable to manage. And sustainability can be young people, all of us, hoping that we work in the right direction. And sustainable life, [...] a sustainable way of living. Then we get down to this more social aspect, how we treat each other, how we look upon other human-beings and nature. There are so many levels of sustainability.	Yes.
	FB	X	X
	FC*	Circularity improves the carbon-footprint. I think more about that, less about social sustainability. Since one works so close to material and [...] trust the company.	Yes.
	FD*	Here we come back to how we define it at Volvo. Carbon-footprint is highly ranked, and being circular, that is very important.	Yes.
Global Procurement	**GA**	X	X
	GB*	[...] there are two parts of it. One when looking at the human part. But sustainability is also the impact on the environment, which is what I am, almost always, thinking about when talking about sustainability.	Yes.
	GC*	[Agreeing with GB] I would also add the pure commercial parts, to be able to do good business. Not buying things too expensive. [...] That is also an important part in this, it has to be sustainable from all our Code of Conduct things, with the environment and the social, but commerciality is also important in the sustainability work. So that you can reinvest in R&D.	Yes.

	GD*	Sustainability is about our climate impact. But it is both climate impact and the impact on nature and humans-beings. That what we do does not have a negative impact on our Earth or our humans.	No. Sustainability at Volvo is more about defining goals and trying to achieve them.
Complete Vehicle Engineering	**HA***	To me, [...] sustainability is to use as little material as possible and make sure that it gets a second life directly after [the use]. And not using single-use products, you could say.	Yes.
	HB*	In symbiosis we have climate, environment, health, and cost, and to be sustainable all of these have to work together.	Yes.

Appendix IX – Sustainability Key Words

This table shows key words used to define sustainability in literature and interviews, as well as their use frequency. The scale used to measure frequency was: *High* = 8-10 times used, *Medium* = 5-7 times used, and *Low* = 2-4 times used. Words written in italics were the words deemed most suitable for a final definition.

Key Words	Frequency
Environment, nature, ecology	High
Social, human rights, human beings, no discrimination, positive impact on society	High
Climate, climate-action, climate neutral, carbon footprint, reducing emissions	Medium
Health, *needs*, necessities, security, no harm	Medium
Circularity, circular economy	Medium
Economy, commerciality, cost, livelihood, good business	Medium
Ethical, fair, ethical and responsible business, moral, the right thing, good people, good business	Low
Minimised impact, little or no impact, little material, maximise resource efficiency, minimise weight and the materials, minimise energy use, minimise emissions and waste	Low
Long life, second life, entire life-cycle, prolonged use	Low
This generation, young people, *generations to come*, future generations	Low
Balance, work together, systems approach	Low
4R's, reuse, remanufacture, recycling,	Low
Earth's resources, natural resources, required resources	Low
Continuity, maintain, intact, replenish	Low
Renewable	Low

Appendix X – Risk Definitions from Interviews

This table shows the answers to interview question 6 and 6a in Appendix V. A list of the participants and their work area are listed in Appendix VI. The participants with a (*) behind their initials have had their answer translated from Swedish to English. The definitions gathered from the knowledge build-up are listed at the bottom of the table. It was not asked whether the participants in the workshop thought Volvo Cars agreed with their definition. *X* indicates that the interviewee was not present when this question was asked.

Work area	Interviewee	Definition	Shared by Volvo?
Vehicle Propulsion	**AA***	"What we absolutely want to avoid is that Volvo is in any way involved in any business which is harmful for life on Earth - humans, animals, plants. [...] The overall risk is that we don't do as well as we can and as possible in this very important field." [...]	Yes.
Vehicle Platform	**BA**	"It has something to do with unintended outcomes. It's basically things that may mean that you do not receive the outcome that you are seeking. [...] But my perception is that our appetite for risk has changed significantly over the last few years. [...] Our senior management seems very open and supportive to trying things, failing and taking risks."	Yes.
Vehicle Tophat	**CA**	"Maybe something with an event that occurs that wasn't expected somehow. [...] Everyone wants to prevent it because in the other case it will cause a lot of troubles and extra work on particular a thing that we don't really have time for."	Yes.
Sustainability & Volvo Cars Strategy	**DA***	*Provided documents visible in the table below.*	Yes.
	DB*	"[...] In some sense, if our climate impact is bigger than what we can handle ourselves and what the surrounding world can accept, than there no longer is a product foundation."	Not really.
	DC*	X	X
Software & Electronics Platform	**EA***	"It is, like I said, with the matter of a risk being a quality risk. How much does the company need to pay because we did a substandard construction? It renders whining customers and we have to pay for their repairs. that is a typical risk for us."	No.

Design	**FA***	"Danger. [...] Risk can also be future and courage, and I think that we need 'risk = courage', but as little danger as possible. [...] If we always weigh in every parameter, we might never go forward."	No.
	FB	X	X
	FC*	"[Agreeing with FD] Yes."	Yes, as far as I know.
	FD*	"Something that can happen if it does not go as it should."	Yes, as far as I know.
Global Procurement	**GA**	X	X
	GB*	"[Agrees with GC] I see it like we have a start somewhere, and a goal, and that which prevents us from getting there, are the risks we see."	Yes, I think so.
	GC*	"[...] We have a target that we want to reach. And than we have where we stand today. So we have a path to how we want to reach our goals and everything that can interfere - all those hurdles on the way are the risks, I would say"	Yes, I think so.
	GD*	"Well, we are having this discussion, risk as a concept [...] A risk is something that can happen, in my opinion. If it has already happened [...] it isn't a risk, but a fact."	No, different units talk about it in different ways.
Complete Vehicle Engineering	**HA***	"To me a risk is that our customers, who owns the cars, experience discomfort or trouble because we use the materials we do, and that must never happen."	Yes.
	HB*	"[...] Risk is somehing that affects something else, positively or negatively. That is what a risk is: an affect, simply put."	No. Different risks are defined in different ways, not all would say "positive".
Knowledge build-up*		"Something which affects humans and the environment, usually negatively."	-
		"Risks with not being able to perform a certain task."	-
		"Something that may occur, the probability is to be calculated"	-
		"An event that occurs and affects a system so that it does not work as intended."	-

In the interview with DA, the interviewee linked to two internal documents which contained risk and risk management definitions, called *VCG Risk Management Directive ver 1.1* and *BMS risk management definitions*. In the table below, the risk definitions from these documents are listed, including their description.

Document	Definitions	Description
VCG Risk Management Directive (Volvo Cars, n.d.-a)	"Potential negative impact on expected results, due to uncertainties"	-
BMS Risk Management (Volvo Cars, n.d.-b)	"Effect of uncertainty on objectives"	*Effect* = deviation from the expected *Objective* = goal, intended outcome
	"A possible event that could cause harm or loss, or affect the ability to achieve objectives."	"A risk is measured by the probability of a threat, the vulnerability of the asset to that threat, and the impact it would have if occurred."
	"[…] uncertainty of outcome"	"[…] can be used in the context of measuring the probability of positive as well as negative outcomes."
	"[…] a measurable deviation from prerequisites that have a negative effect on the targets of a program."	"A risk can either be an actual occurrence/ deviation or a negative prognosis of development."
	"Undesired event which under other circumstances could have led to a near miss or accident."	-

Appendix XI – Risk Key Words

This table shows key words used to define risk in literature, interviews and workshop 1, as well as their use frequency. The scale used to measure frequency was: *High* = 9-18 times used, *Medium* = 5-8 times used, and *Low* = 1-4 times used. Words written in italics were the words deemed most suitable for a final definition.

Key Words	Frequency
Uncertainty, *event*, situation, may occur, something that can happen,	High
Harm, harmful, danger, negative, damage, hazard, *adverse*	High
affect, effect, *impact*	High
Expected results, *objectives*, goals, prerequisites	Medium
Outcomes, *consequences*	Medium
Probability, likelihood	Medium
Unintended, unexpected	Low
Interfere	Low
Circumstance	Low
Threat	Low
Undesired, unwanted, deviation	Low
Value	Low
Severity	Low

Appendix XII – Objects at Risk Pre-Workshop

Below, the organisation of the objects at risk is shown. The tables show level 2, 3, and 4 of the objects at risk.

1. Objects at Risk of the Nature System

1.1. Climate (Level 1)

Level 2	Level 3	Level 4
1.1.1. Weather	Temperature	Concentration of GHG:s
	Precipitation	Bodies of water for evaporation Humidity
	Wind patterns	Air pressure
1.1.2. Atmosphere	Stratospheric ozone layer	Stratospheric ozone
	Albedo	Clouds Ice sheets

1.2. Land (Level 1)

Level 2	Level 3	Level 4
1.2.1. Terrestrial biodiversity	Legally protected land areas	Legally protected mountain area Legally protected forest area Legally protected plain areas ...
	Threatened terrestrial species	Orangutan Polar bear Cork tree ...
1.2.2. Terrestrial ecosystem services	Terrestrial regulating services	Pollination ...
	Terrestrial supporting services	Nutrient cycle ...
	Terrestrial cultural services	Historical settlements ...
	Terrestrial provisioning services	Food supply from terrestrial life ...
1.2.3. Soil	Soil fertility	Soil quality Soil organic matter
1.2.4. Natural terrestrial resources	Terrestrial biotic resources	Terrestrial fossil resources Terrestrial flora Terrestrial fauna
	Terrestrial abiotic resources	Bodies of water resources Air Terrestrial rare-earth elements and metals

1.3. Freshwater (Level 1)

Level 2	Level 3	Level 4
1.3.1. Freshwater biodiversity	Legally protected freshwater areas	Legally protected rivers Legally protected lakes

		...
	Threatened freshwater species	American crocodile Manatee ...
1.3.2. Freshwater ecosystem services	Freshwater regulating services	Water runoff control ...
	Freshwater supporting services	Water cycling ...
	Freshwater cultural services	Aesthetic values ...
	Freshwater provisioning services	Freshwater ...
1.3.3. Natural freshwater resources	Freshwater biotic resources	Aquatic fossil resources Aquatic flora Aquatic fauna
	Freshwater abiotic resources	Aquatic rare-earth elements and metals The water cycle

1.4. Ocean (Level 1)

Level 2	Level 3	Level 4
1.4.1. Ocean biodiversity	Legally protected ocean areas	Coral reefs ...
	Threatened ocean species	Whale shark Giant Tortoise ...
1.4.2. Ocean ecosystem services	Ocean regulating services	Climate regulation ...
	Ocean supporting services	Photosynthesis by marine life ...
	Ocean cultural services	Scuba diving ...
	Ocean provisioning services	Fishery ...
1.4.3. Natural ocean resources	Ocean biotic resources	Aquatic fossil resources Aquatic flora Aquatic fauna
	Ocean abiotic resources	Aquatic rare-earth elements and metals The water cycle

2. Objects at Risk of the Social System

2.1. Humans (Level 1)

Level 2	Level 3	Level 4
2.1.1. Workers (in-house and supplier)	Workforce facilities	Accommodation for workers Electricity in working facilities Water in working facilities Areas for food storage, eating, and resting
	Workers' health and safety	Work-life balance Job satisfaction Air quality in work environment Water quality in work environment Water quantity for workers Water supply for workers

		Workers' privacy Migrant workers Workers' liberty
	Workers' freedom of speech and	Whistleblower
2.1.2. Indigenous Peoples	Indigenous Peoples' health and safety	Air quality on Indigenous land Water quality on Indigenous land Indigenous populations of the Global Adequate standards of living Indigenous coastal residents
	Indigenous livelihood	Indigenous local workforce Indigenous local procurement Legally protected areas for Indigenous livelihood Economy of Indigenous families
	Indigenous cultural heritage	Legally protected areas with Indigenous cultural heritage
	Material and immaterial resources for	Water quantity on Indigenous land Soil quality on Indigenous land Indigenous land quality Biotic resources on Indigenous land Abiotic resources on Indigenous land Food security for Indigenous Peoples Water supply for Indigenous Peoples
	Indigenous Peoples' freedom of speech	Indigenous self-determination
2.1.3. Community	Community health and safety	Community air quality Community water quality Community liberty Adequate standards of living in the community Communities of the Global South Coastal communities
	Community livelihood	Local workforce Legally protected areas for livelihood Local procurement Economy of families in the community
	Community cultural heritage	Legally protected areas with cultural heritage
	Material and immaterial resources for	Water quantity in the community Soil quality in the community Land quality in the community Biotic resources in the community Abiotic resources in the community Food security in the community Water supply in the community
	Institutional capacity	Economic growth in the community Education possibilities in the community Community development
	Freedom of speech and expression in the	Diversity in community
	Renewable and/or carbon neutral energy	Wind power supply Hydro power supply Bio-fuel supply Nuclear power supply
2.1.4. Discriminated groups	Women and girls	Girls' education Livelihood for women Freedom of speech and expression for women and girls
	Transgender people	Livelihood for transgender people Freedom of speech and expression for transgender

	Ethnic minorities	Livelihood for ethnic minorities Freedom of speech and expression for ethnic minorities
	Religious groups	Livelihood for religious groups Freedom of speech and expression for religious groups
	Disabled people	Livelihood for differently abled people Freedom of speech and expression for disabled people
	LGBQIA+ people	Livelihood for LGBQIA+ people Freedom of speech and expression for LGBQIA+ people
2.1.5. Children	Children's health and safety	Water quality for children Water quantity for children Air quality for children Water supply for children Children's education Children's liberty Children of the Global South Coast residing children
	Children's freedom of speech and	Children's diversity

2.2. Business (Level 1)

Level 2	Level 3	Level 4
2.2.1. Confidentiality	Cyber security for information	Sensitive information Personal information Business privacy
2.2.2. Customer	Customer well-being	Customer safety Customer comfort
	Customer relation	Customer service Customer treatment
2.2.3. Supply chain	Suppliers	Local suppliers Long-term suppliers Transparency towards/from suppliers Traceability of supply chain Social data accuracy from suppliers
	Legal compliance	Tax payments Social license to operate Historical liabilities
	Critical raw material use	Demand
	International relations	Relation to producing countries Relation to reserve holding countries Relation to waste handling countries
2.2.4. Stakeholders	Stakeholder relation	Transparency towards stakeholders Traceability for stakeholders Stakeholder treatment
2.2.5. Continuous improvement	Competence	Knowledge Creativity Cooperation Experience
	Strategy	Goals Communication R&D
	Economics	Business investments Sales

3. Objects at Risk of the Technical System

3.1. Land (Level 1)

Level 2	Level 3	Level 4
3.1.1. Agricultural land	Agricultural soil	Food security
3.1.2. Domesticated animals	Domesticated animal health	Air quality for domesticated animals
		Domesticated animals' freedom from hunger and thirst
		Domesticated animals' freedom from discomfort
		Domesticated animals' freedom from pain, injury, and disease
		Domesticated animals' freedom to express normal behaviour
		Domesticated animals' freedom from fear and distress

3.2. Waste Treatment (Level 1)

Level 2	Level 3	Level 4
3.2.1. Waste water treatment plant	Basic waste water treatment supplies	Water supply to WWTP
		Adequate WWTP equipment and
3.2.2. Solid waste treatment plant	Basic solid waste treatment supplies	Water supply to SWTP
		Adequate SWTP equipment and
3.2.3. Recycling plant	Basic recycling supplies	Water supply to recycling plant
		Electricity supply to recycling plant
		Household waste recycling centre

3.3. Product (Level 1)

Level 2	Level 3	Level 4
3.3.1. Manufacturing process	Assembly line	Water supply to assembly
		Electricity supply to assembly
		Adequate assembly equipment and machinery
	Components	Battery
3.3.2. Refining process	Conversion process	Water supply to refining
		Electricity supply to refining
		Raw material supply
		Adequate refining equipment and machinery
3.3.3. Supply chain	Logistics	Deliveries
3.3.4. Extraction process	Mines	Water supply to mines
		Electricity supply to mines
		Adequate mining equipment and machinery
		Drainage
		Mineral supply
	Fossil extraction	Water supply to extraction site
		Electricity supply to extraction site
		Adequate mining equipment and machinery
		Fossil resources supply
	Forestry	Water supply to forestry

		Electricity supply to forestry Adequate mining equipment and machinery Biomass supply
3.3.5. Product quality	Product lifetime	Energy efficiency Durable materials

3.4. Materials (Level 1)

Level 2	Level 3	Level 4
3.4.1. Scarce materials	Scarce mined materials	Scarce rare-earth elements and metals
	Non-mined materials	Accessible freshwater
3.4.2. Renewable materials	Plant-based materials	Bioplastic Textile Wood
	Animal-based materials	Wool Leather
3.4.3. Circular materials	Recyclable materials	Aluminium ...
	Recycled materials	Recycled plastic ...
	Reusable materials	Reused components ...
3.4.5. Non-renewable materials	Fossil materials	Plastics
	Metals	Non-renewable rare-earth elements and Steel ...
	Virgin materials	Virgin material reserves
	Critical raw materials	Unique material properties

3.5. Energy Production Facilities (Level 1)

Level 2	Level 3	Level 4
3.5.1. Renewable energy production	Wind turbines	Steel for wind turbines
	Solar cells	Silicon semiconductors ...
	Hydropower plants	Water supply for hydropower plants ...
	Biofuel facility	Biomass supply for fuel ...
3.5.2. Carbon neutral energy production	Wind turbines	Steel for wind turbines
	Solar cells	Silicon semiconductors ...
	Nuclear power plants	Nuclear fuel supply ...

3.6. Business Apparatuses (Level 1)

Level 2	Level 3	Level 4
3.6.1. IT-systems	Cyber security for functionality	Computer-driven processes ...
	Databases	Data accuracy for functionality
3.6.2. Basic supplies	Basic supplies for performance	Tools Office supplies Machinery
	Basic supplies for safety	Safety equipment

3.7. Infrastructure (Level 1)

Level 2	Level 3	Level 4
3.7.1. Transportation infrastructure	Non-stationary transportation	Transport fleet
	Stationary transportation infrastructure	Roads
		Bridges
3.7.2 On-site infrastructure	Facilities	Storage
		Factory

Appendix XIII – Objects at Risk Post-Workshop

The objects at risk left after the first exercise, and their sublevels, is shown below. The tables show level 2, 3, and 4 of the objects at risk and the number in the parenthesis is the number of votes it got. Those having a star were the ones with the highest number of votes, and the ones that were chosen for the final model.

1. Objects at Risk of the Nature System

1.1. Climate (Level 1)

Level 2	Level 3	Level 4
1.1.1. *Atmosphere (9)	Stratospheric ozone layer	Stratospheric ozone
	Albedo	Clouds
	Low CO2 concentrations	
1.1.2. *Ocean (7)		
1.1.3. *Fresh water (8)		
1.1.4. *Land & soil (9)	Soil fertility	Soil quality
		Soil organic matter

1.2. Ecosystem services (Level 1)

Level 2	Level 3	Level 4
1.2.1. *Biodiversity (6)	Terrestrial biodiversity	Legally protected land areas
		Threatened terrestrial species
	Freshwater biodiversity	Legally protected freshwater areas
		Threatened freshwater species
	Ocean biodiversity	Legally protected ocean areas
		Threatened ocean species
1.2.2. *Natural resources (6)	Natural ocean resources	Biotic ocean resources
		Aquatic ocean resources
	Natural freshwater resources	Freshwater biotic resources
	Natural terrestrial resources	Terrestrial biotic resources

2. Objects at Risk of the Social System

2.1. Humans (Level 1)

Level 2	Level 3	Level 4
2.1.1. *Workers and discriminated	Workforce facilities	Accommodation for workers
		Water in working facilities
		Basic working supplies
		Areas for food storage, eating, and resting
	Workers' health and safety	Work-life balance
		Job satisfaction
		Air quality in work environment
		Water quality in work environment
		Water quantity for workers
		Water supply for workers
		Workers' privacy
		Migrant workers

		Workers' liberty
	Workers' freedom of speech and	Whistle-blower Diversity in workplace
	Women and girls	Girls' education Livelihood for women Freedom of speech and expression for women and girls
	Transgender people	Livelihood for transgender people Freedom of speech and expression for transgender
	Ethnic minorities	Livelihood for ethnic minorities Freedom of speech and expression for ethnic minorities
	Religious groups	Livelihood for religious groups Freedom of speech and expression for religious groups
	Disabled people	Livelihood for differently abled people Freedom of speech and expression for disabled people
	LGBQIA+ people	Livelihood for LGBQIA+ people Freedom of speech and expression for LGBQIA+ people
2.1.2. *Community, Indigenous	Indigenous Peoples' health and safety	Air quality on Indigenous land Indigenous Peoples' liberty Indigenous populations of the Global South Adequate standards of living Indigenous coastal residents
	Indigenous livelihood	Indigenous local workforce Indigenous local procurement Legally protected areas for Indigenous livelihood Economy of Indigenous families
	Indigenous cultural heritage	Legally protected areas with
	Material and immaterial resources for	Water quantity on Indigenous land Soil quality on Indigenous land Indigenous land quality Biotic resources on Indigenous land Abiotic resources on Indigenous land Food security for Indigenous Peoples Water supply for Indigenous Peoples
	Indigenous Peoples' freedom of speech	Indigenous self-determination
	Community health and safety	Community air quality Community water quality Community liberty Adequate standards of living in the Communities of the Global South Coastal communities
	Community livelihood	Local workforce Legally protected areas for livelihood Local procurement Economy of families in the community
	Community cultural heritage	Legally protected areas with cultural
	Material and immaterial resources for	Water quantity in the community Soil quality in the community Land quality in the community Biotic resources in the community Abiotic resources in the community Food security in the community

		Water supply in the community
	Institutional capacity	Economic growth in the community Education possibilities in the community Community development
	Freedom of speech and expression in	Diversity in community
	Renewable and/or carbon neutral	Wind power supply Hydro power supply Bio-fuel supply Nuclear power supply
2.1.3. *Children (7)	Children's health and safety	Water quality for children Water quantity for children Air quality for children Water supply for children Children's education Children's liberty Children of the Global South Coast residing children
	Children's freedom of speech and	Children's diversity

2.2. Business (Level 1)

Level 2	Level 3	Level 4
2.2.1. Customer (5)	Customer well-being	Customer safety Customer comfort
	Customer relation	Customer service Customer treatment
2.2.2. *Supply chain (10)	Suppliers	Local suppliers Long-term suppliers Transparency towards/from suppliers Traceability of supply chain Social data accuracy from suppliers
	Legal compliance	Tax payments Social license to operate Historical liabilities
	Critical raw material use	Demand
	International relations	Relation to producing countries Relation to reserve holding countries Relation to waste handling countries

3. Objects at Risk of the Technical System

3.1. Product (Level 1)

Level 2	Level 3	Level 4
3.1.1. *Product quality (12)	Product longevity	Energy efficiency Durable materials
	Material properties	

3.2. Materials and supply chain (Level 1)

Level 2	Level 3	Level 4
	Logistics	Deliveries
3.2.2. *Scarce materials (7)	Scarce mined materials	Scarce rare-earth elements and metals
	Non-mined materials (example	Accessible freshwater
3.2.3. Renewable materials (3)	Plant-based materials	Bioplastic Textile

		Wood
	Animal-based materials	Wool
3.2.4 *Circular and non-renewable	Recyclable materials	Aluminium
	Recycled materials	Recycled plastic ...
	Reusable materials	Reused components ...
	Fossil materials	Plastics
	Metals	Non-renewable rare-earth elements and metals Steel ...
	Virgin materials	Virgin material reserves
	Critical raw materials	Unique material properties
3.2.5. *Extraction and refining	Mines	Water supply to mines Adequate mining equipment and machinery Drainage Mineral supply
	Fossil extraction	Water supply to extraction site Electricity supply to extraction site Adequate mining equipment and machinery Fossil resources supply
	Forestry	Water supply to forestry Electricity supply to forestry Adequate mining equipment and machinery Biomass supply
	Conversion process	Water supply to refining Electricity supply to refining Raw material supply Adequate refining equipment and machinery

3.3. Production facilities (Level 1)

Level 2	Level 3	Level 4
3.3.1. *Carbon neutral and renewable	Wind turbines	Steel for wind turbines
	Solar cells	Silicon semiconductors ...
	Nuclear power plants	Nuclear fuel supply ...
	Hydropower	
3.3.2. Wastewater treatment plant	Basic wastewater treatment supplies	Water supply to WWTP Adequate WWTP equipment and
3.3.3. Recycling plant (4)	Basic recycling supplies	Water supply to recycling plant Electricity supply to recycling plant Household waste recycling centre
	Basic solid waste treatment supplies	Water supply to SWTP Adequate SWTP equipment and machinery
3.3.4. Waste management (4)		

3.4. Apparatuses and infrastructure (Level 1)

Level 2	Level 3	Level 4
3.4.1. IT-systems (3)	Cyber security for functionality	Computer-driven processes ...
	Databases	Data accuracy for functionality

Appendix XIV – Risk Categories from Own Contributions

The table below lists the authors own contributions to fill gaps in the cause-effect chains.

OR – Object at Risk
RR – Link of Relationship of Risk
RO – Risk Object

Risk category / **Type**	**OR**	**RR**	**RO**
Freshwater	X		
Plant-based material	X		
Animal-based material	X		
Wind turbines	X		
Solar cells	X		
Nuclear power plants	X		
Hydropower	X		
Increased land use		X	
Negative impacts on atmosphere		X	
Bad decisions		X	
Negative impacts on the ocean		X	
Increased water use		X	
Negative impacts on freshwater		X	
Wastewater runoff		X	
Negative impacts on land and soil		X	
Habitat loss		X	
Negative impacts on biodiversity		X	
Biomass loss		X	
High resource use		X	
Radiation leakage		X	
Too high temperature		X	
Lack of light		X	
Worsened family economies		X	
Safety issues		X	
Destruction		X	
Conflicts with supplying countries		X	
Increasing need for cheap labor		X	
Lack of energy access		X	
Loss of livelihood		X	
Food insecurity		X	
Dependency on CRM		X	
Degrading land and water quality		X	
Increased livestock keeping		X	
Natural disasters		X	
Compromising information		X	
Shorter lifecycle		X	
Not trying to find new solutions		X	
Depletion of scarce matrials		X	
Increasing demand of scarce materials		X	

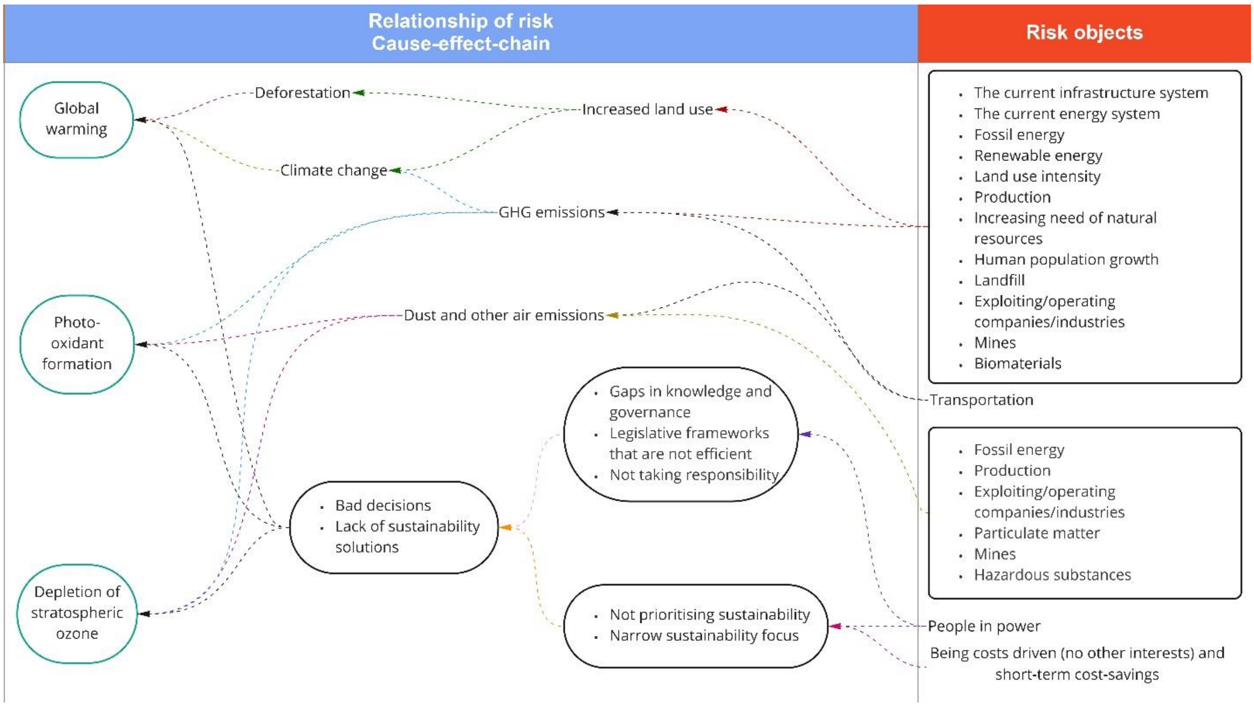
Depletion of non-renewable materials		X	
Increasing demand of circular and non-renewable		X	
Rejection of recycled material		X	
High material use		X	
High demand for certain materials		X	
Increased water temperature		X	
Human populations of the Global North			X
Cyber security	X		
Food habits of the Global North			X

Appendix XV – The Final Model

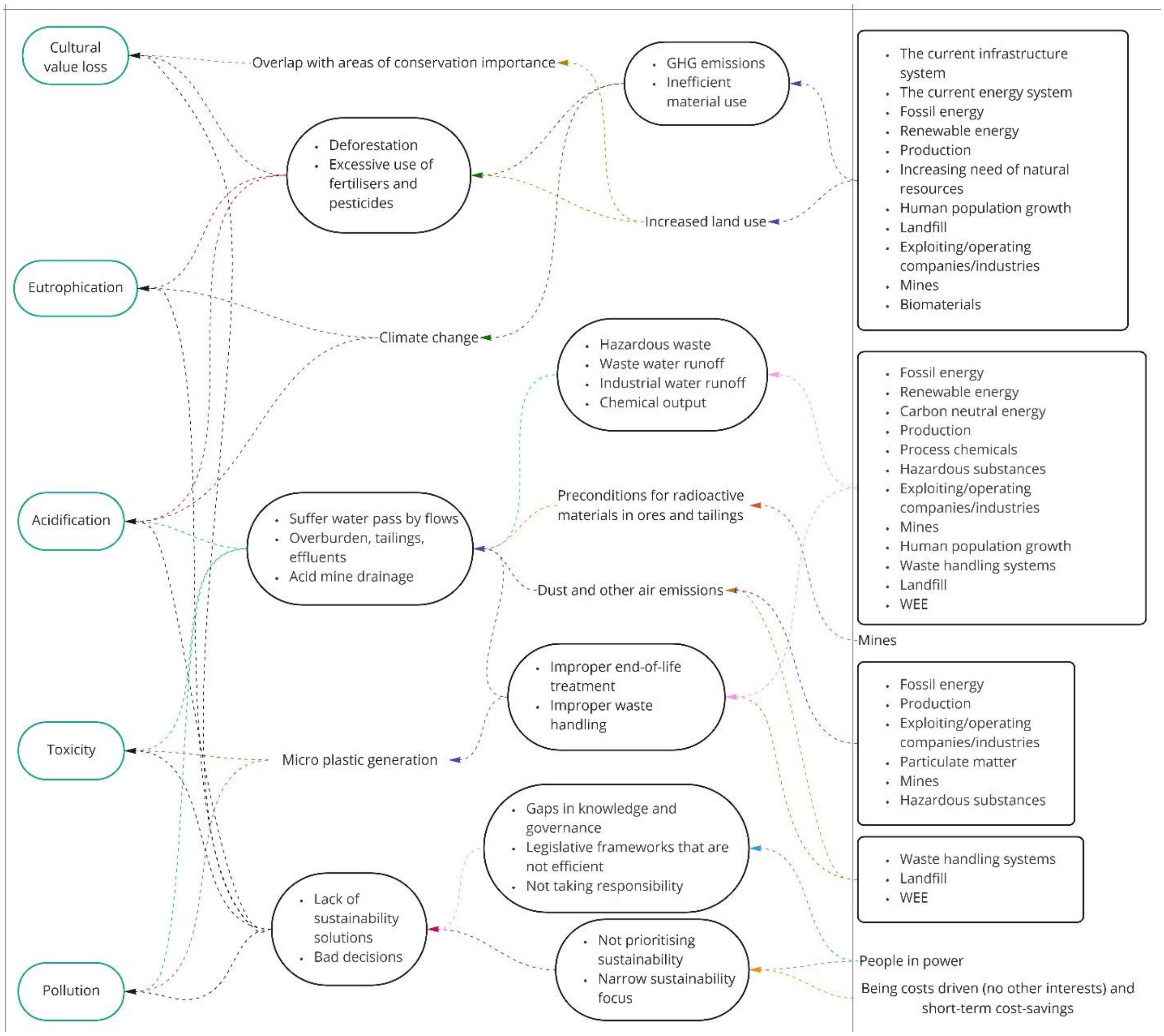
The final model will be shown in the figures below. The model is read from left to right, starting with the object at risk, followed by the effects that could potentially cause harm. The risk object is seen in the column to the right. The arrows are following the opposite direction solely to indicate which effects are caused by certain risk objects. The colours of the arrows indicate the previous risk relation/risk object. The objects at risk are not visible in each figure but stated in the heading above. The cause-effect chains concern the object at risk at level 2.

1. The Nature System

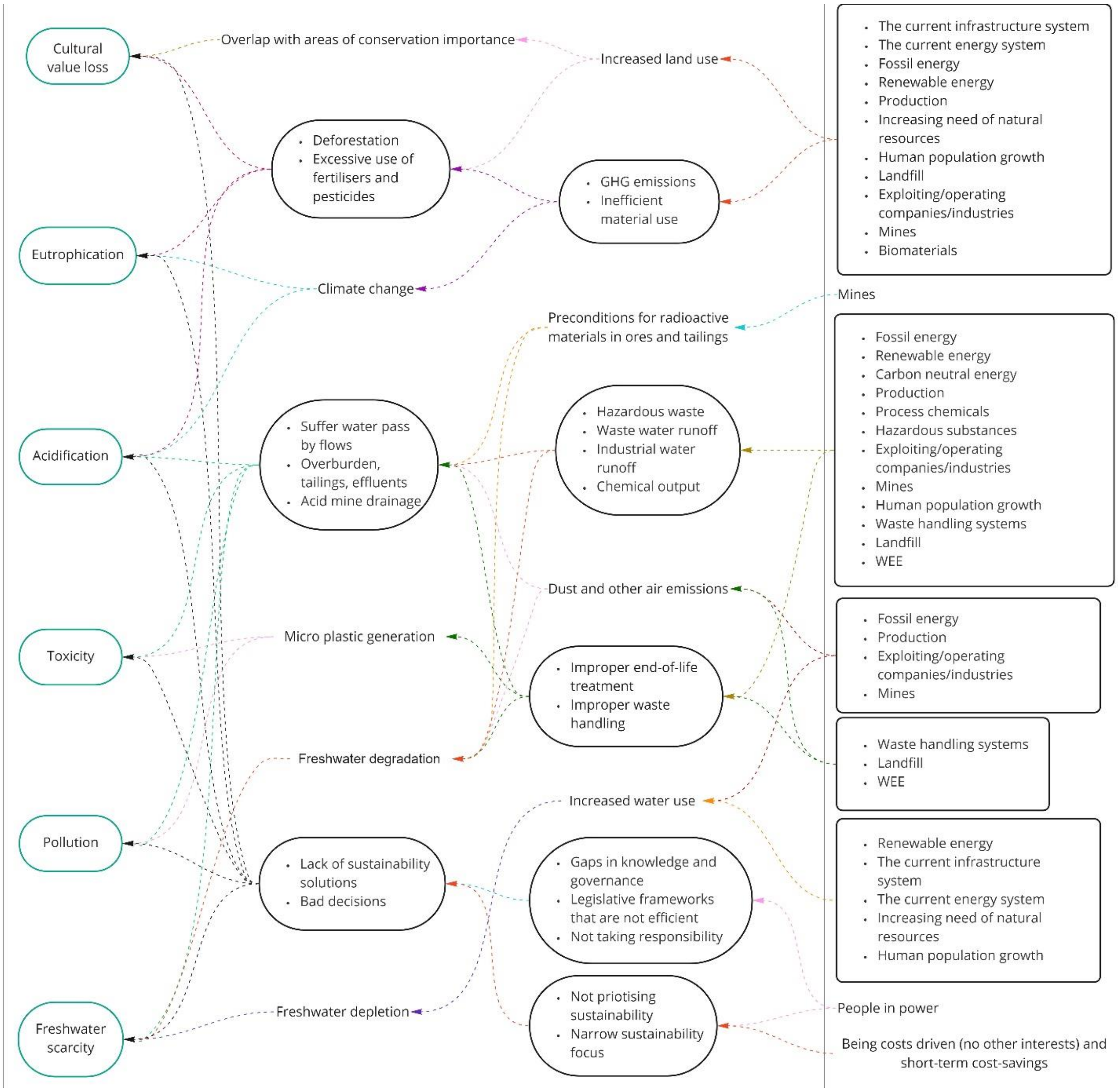
Level 1: Climate – *Level 2: Atmosphere*



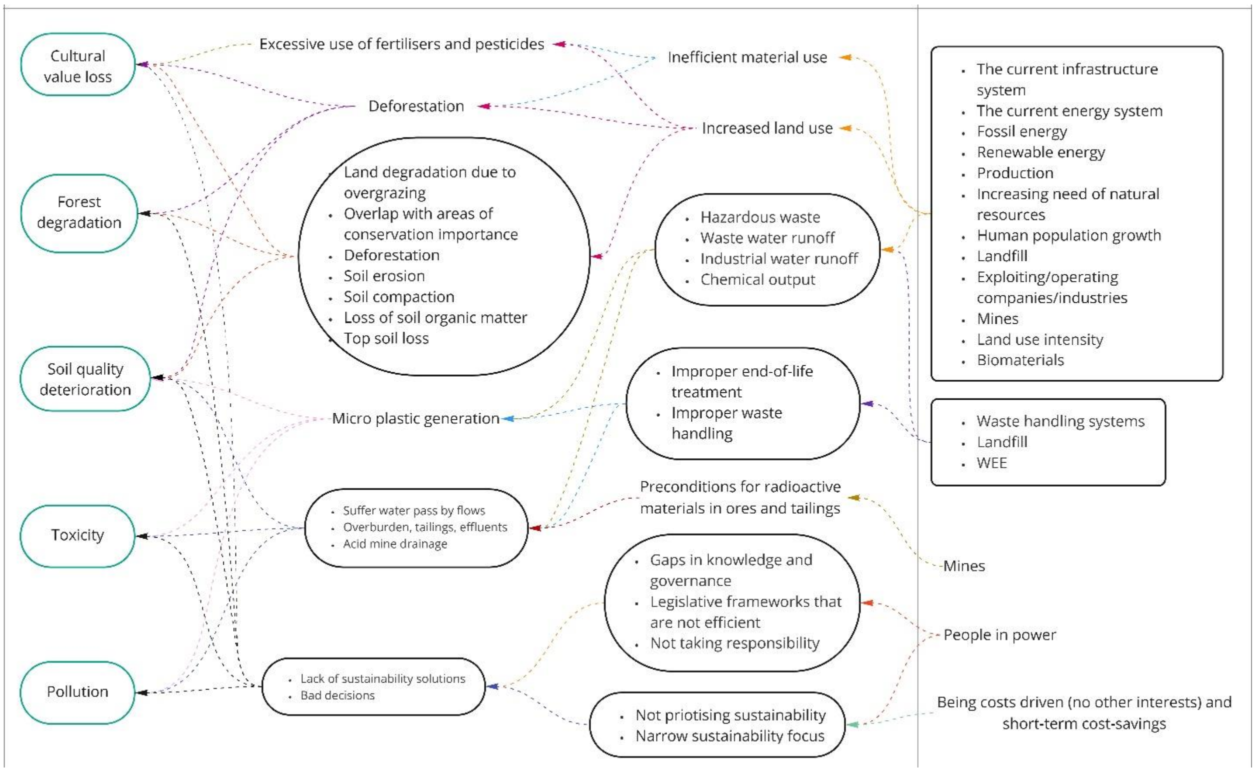
Level 1: Climate – *Level 2: Ocean*



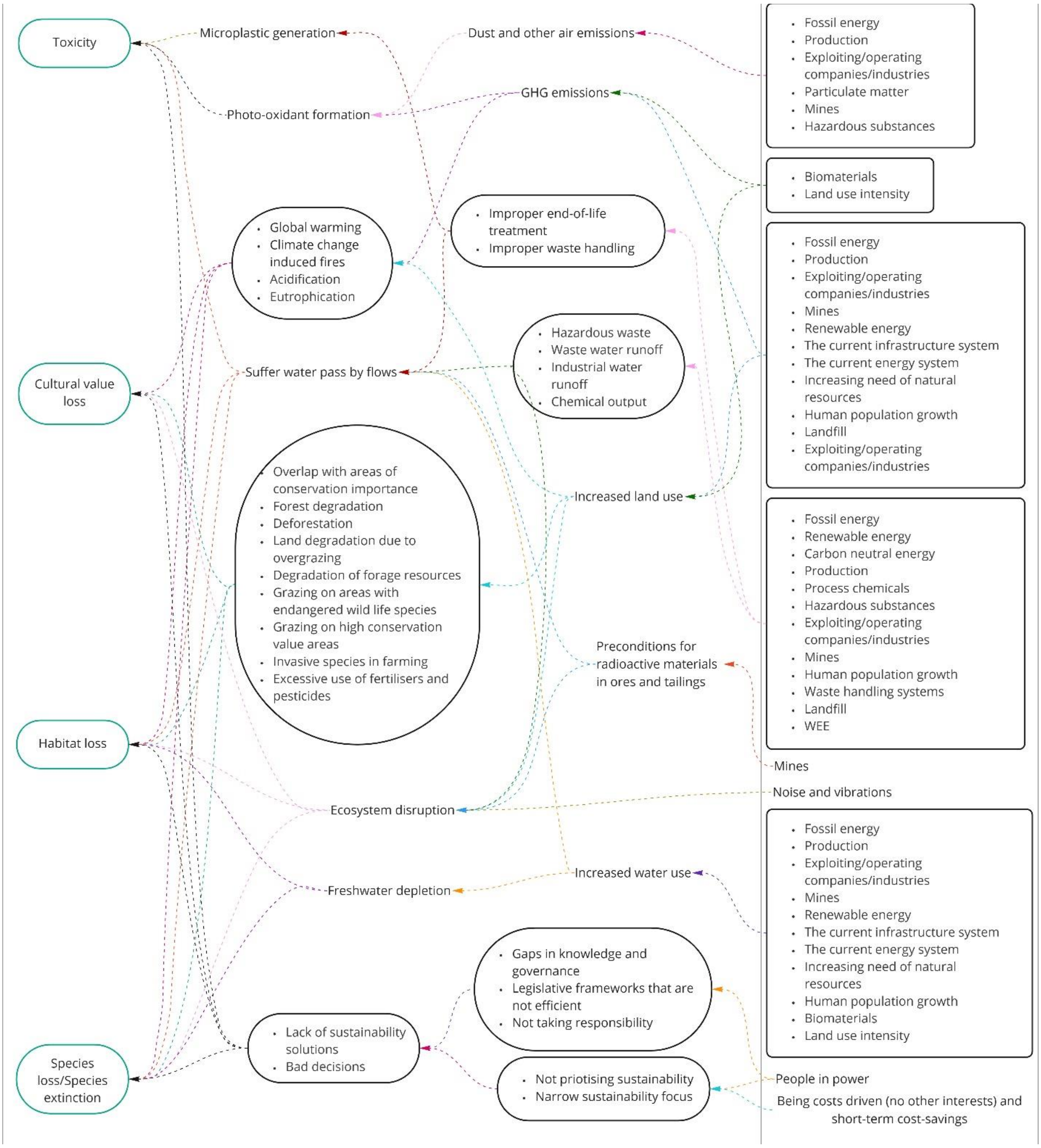
Level 1: Climate – *Level 2: Freshwater*



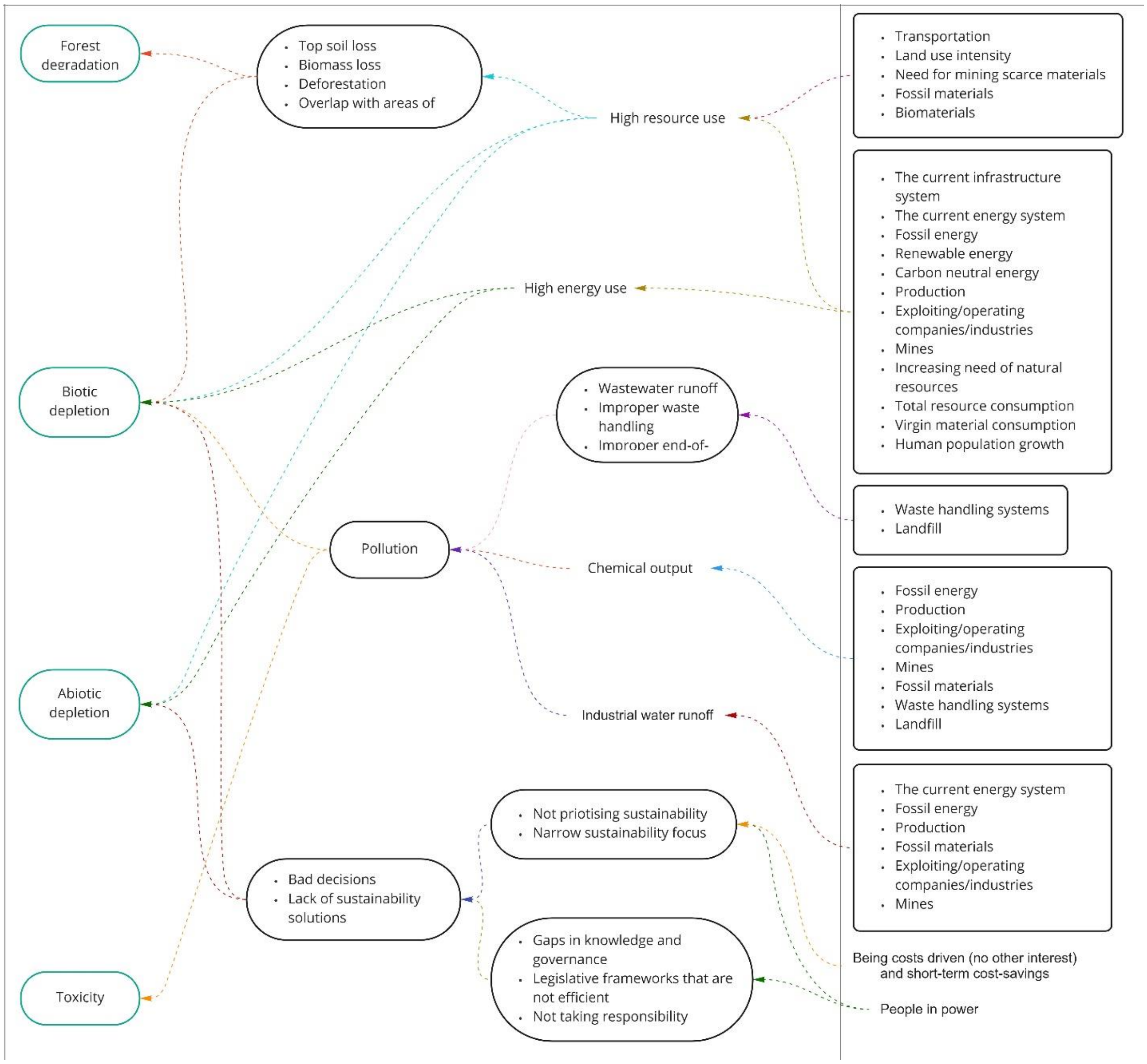
Level 1: Climate – *Level 2: Land & Soil*



Level 1: Ecosystem Services – *Level 2: Biodiversity*

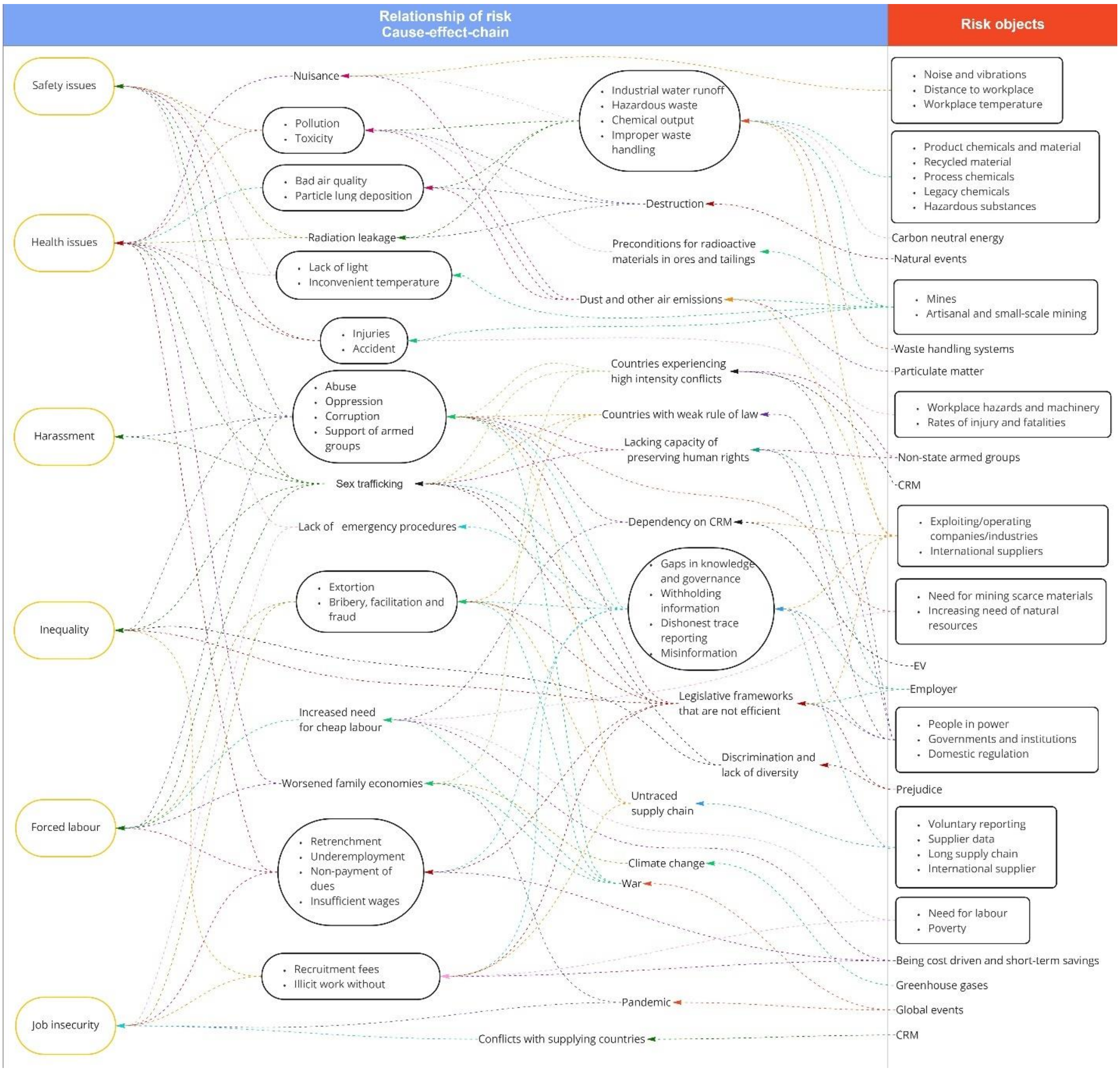


Level 1: Ecosystem Services – *Level 2: Natural Resources*

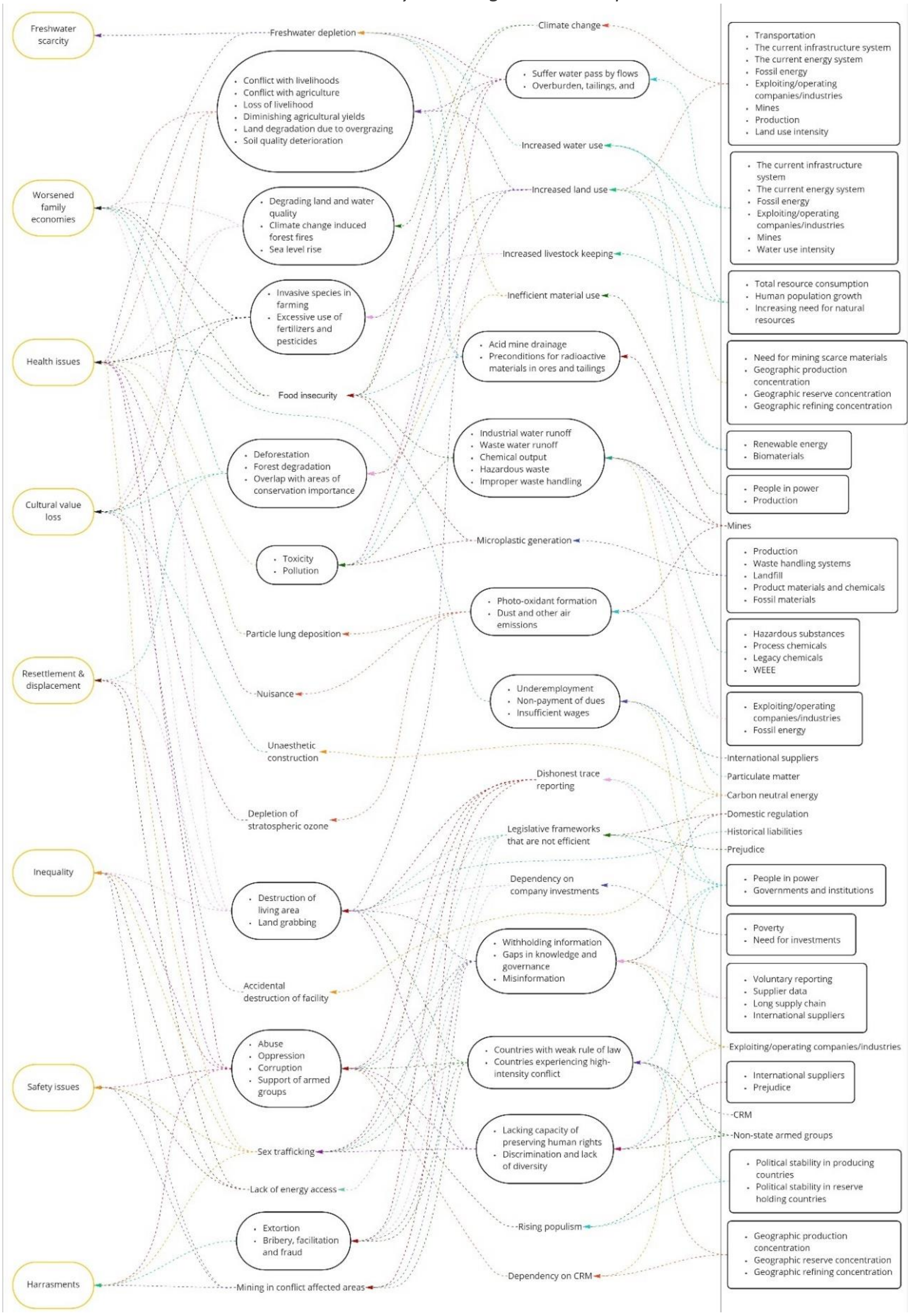


2. The Social System

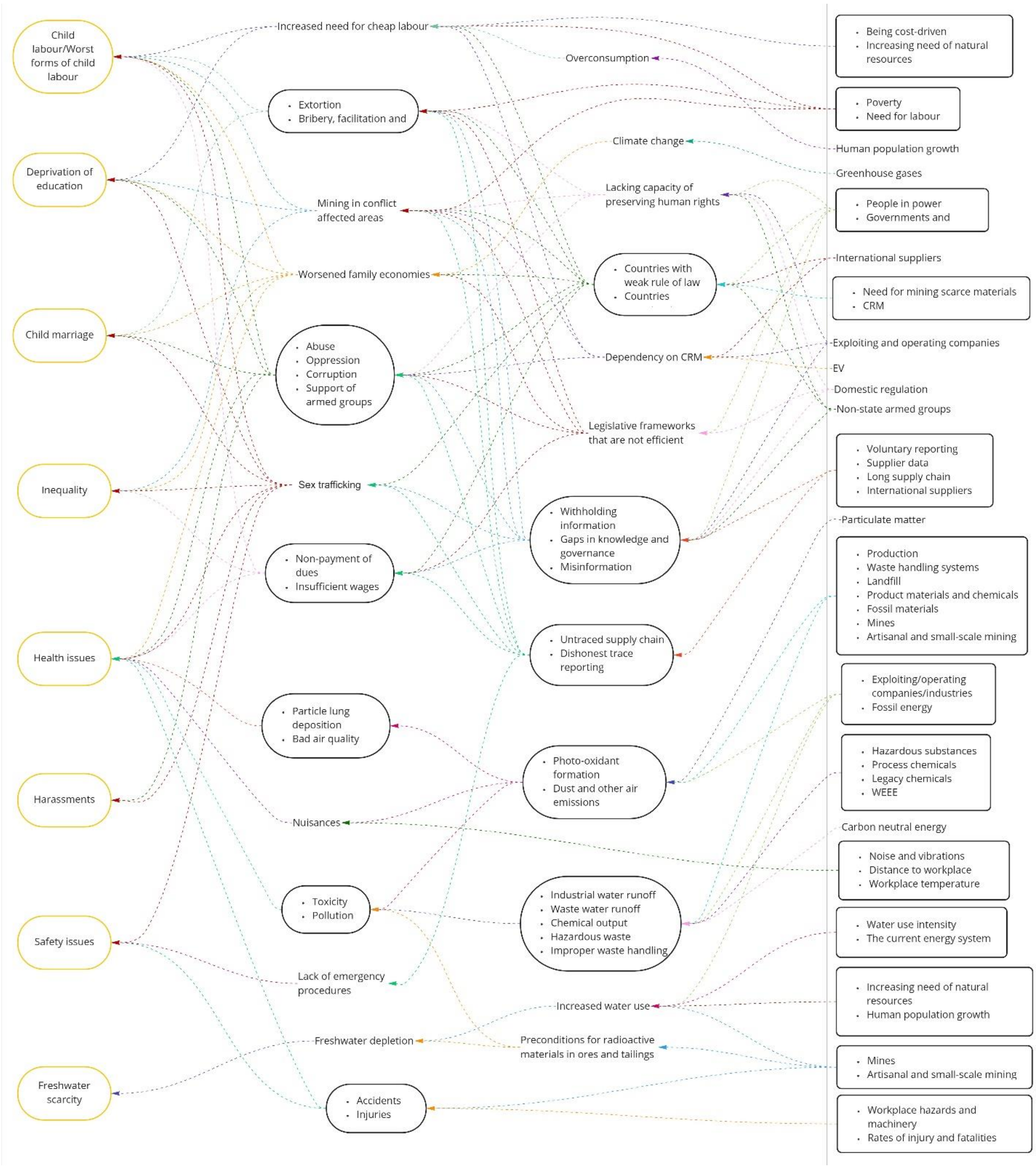
Level 1: Humans – *Level 2: Workers*



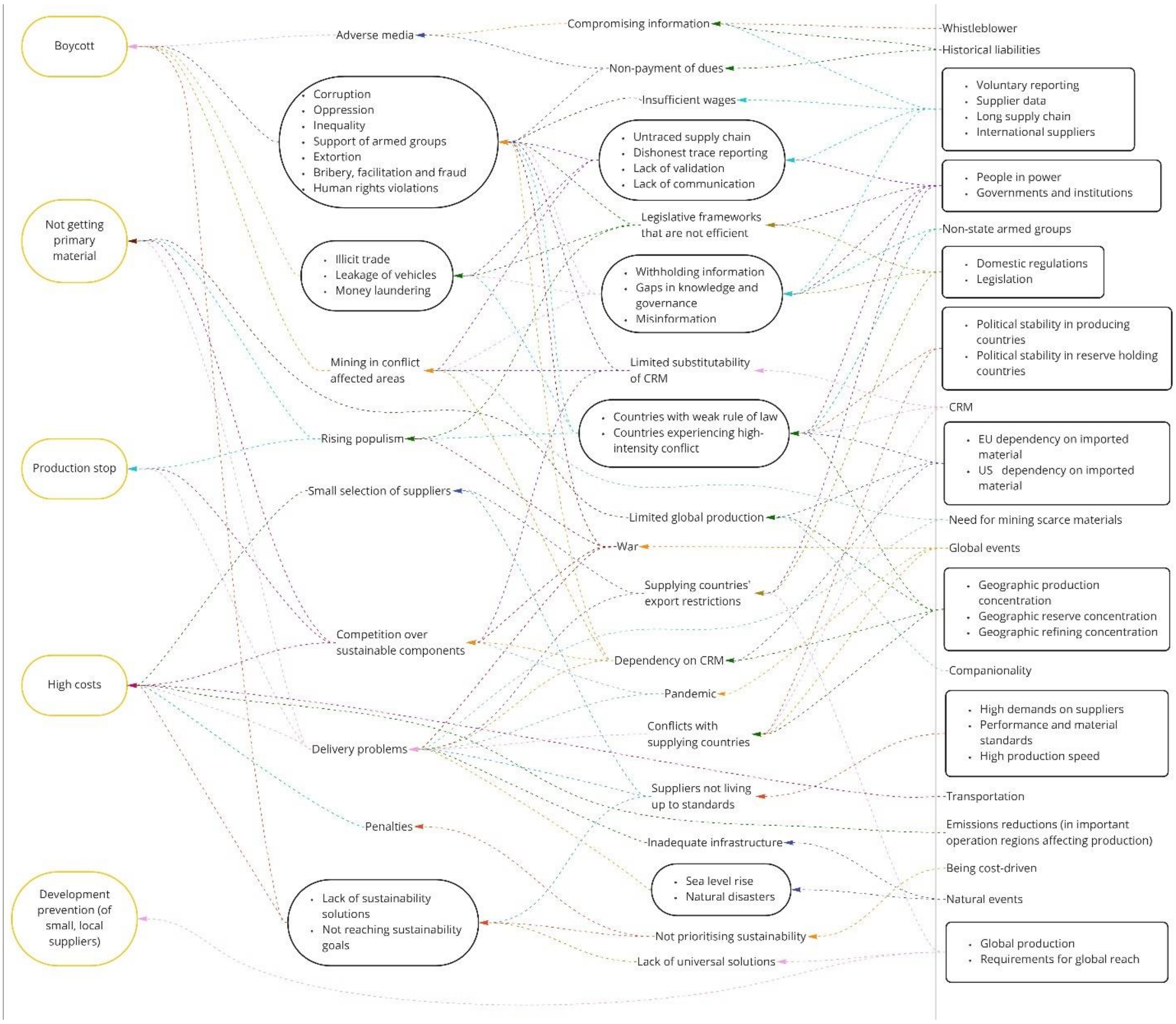
Level 1: Humans – *Level 2: Community & Indigenous Peoples*



Level 1: Humans – *Level 2: Children*

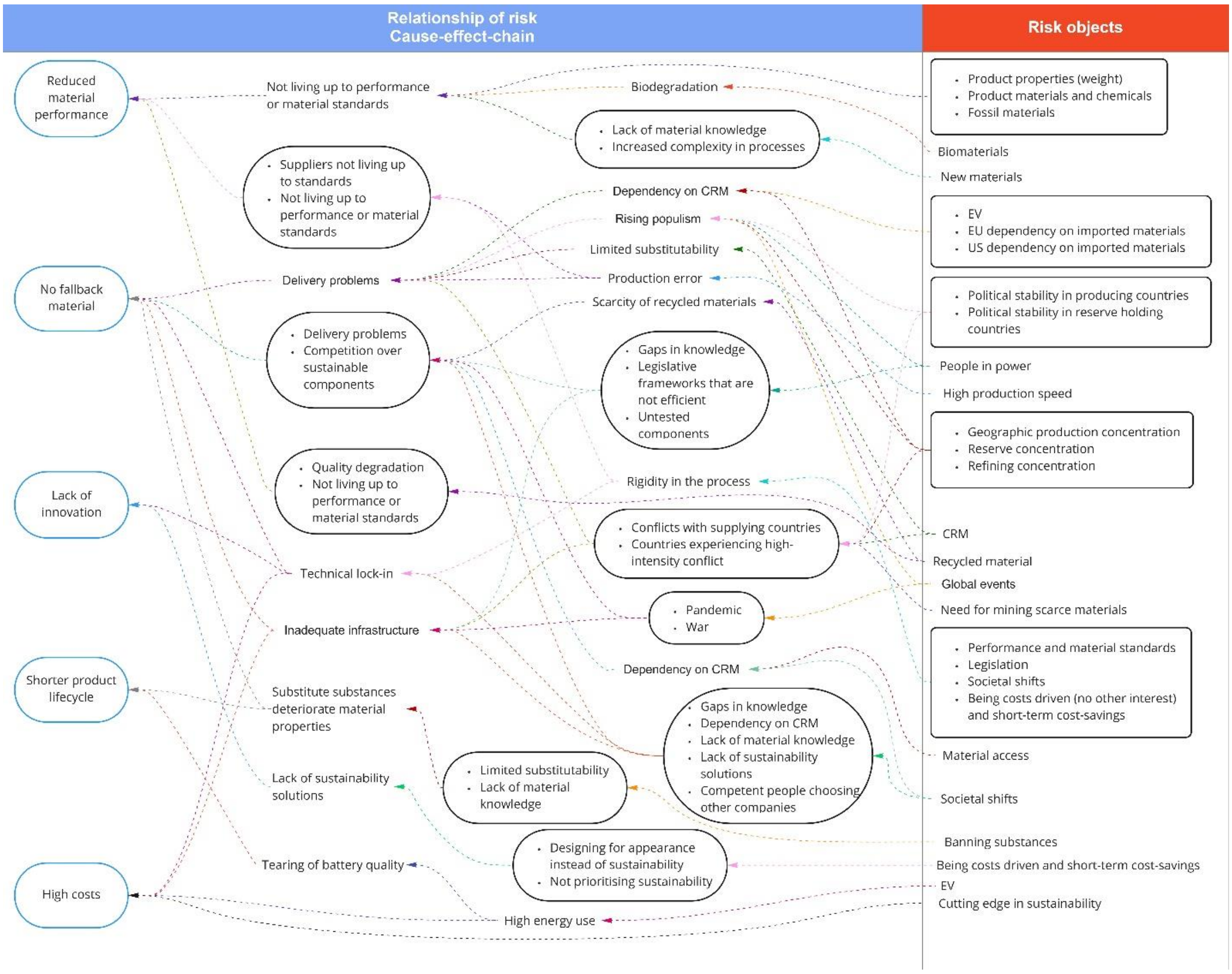

Child labour/Worst forms of child labour
Deprivation of education
Child marriage
Inequality
Health issues
Harassments
Safety issues
Freshwater scarcity
Increased need for cheap labour
Extortion
Bribery, facilitation and
Mining in conflict affected areas
Worsened family economies
Abuse
Oppression
Corruption
Support of armed groups
Sex trafficking
Non-payment of dues
Insufficient wages
Particle lung deposition
Bad air quality
Nuisances
Toxicity
Pollution
Lack of emergency procedures
Freshwater depletion
Accidents
Injuries
Overconsumption
Climate change
Lacking capacity of preserving human rights
Countries with weak rule of law
Countries
Dependency on CRM
Legislative frameworks that are not efficient
Withholding information
Gaps in knowledge and governance
Misinformation
Untraced supply chain
Dishonest trace reporting
Photo-oxidant formation
Dust and other air emissions
Industrial water runoff
Waste water runoff
Chemical output
Hazardous waste
Improper waste handling
Increased water use
Preconditions for radioactive materials in ores and tailings
Being cost-driven
Increasing need of natural resources
Poverty
Need for labour
Human population growth
Greenhouse gases
People in power
Governments and
International suppliers
Need for mining scarce materials
CRM
Exploiting and operating companies
EV
Domestic regulation
Non-state armed groups
Voluntary reporting
Supplier data
Long supply chain
International suppliers
Particulate matter
Production
Waste handling systems
Landfill
Product materials and chemicals
Fossil materials
Mines
Artisanal and small-scale mining
Exploiting/operating companies/industries
Fossil energy
Hazardous substances
Process chemicals
Legacy chemicals
WEEE
Carbon neutral energy
Noise and vibrations
Distance to workplace
Workplace temperature
Water use intensity
The current energy system
Increasing need of natural resources
Human population growth
Mines
Artisanal and small-scale mining
Workplace hazards and machinery
Rates of injury and fatalities

Level 1: Business – *Level 2: Supply Chain*

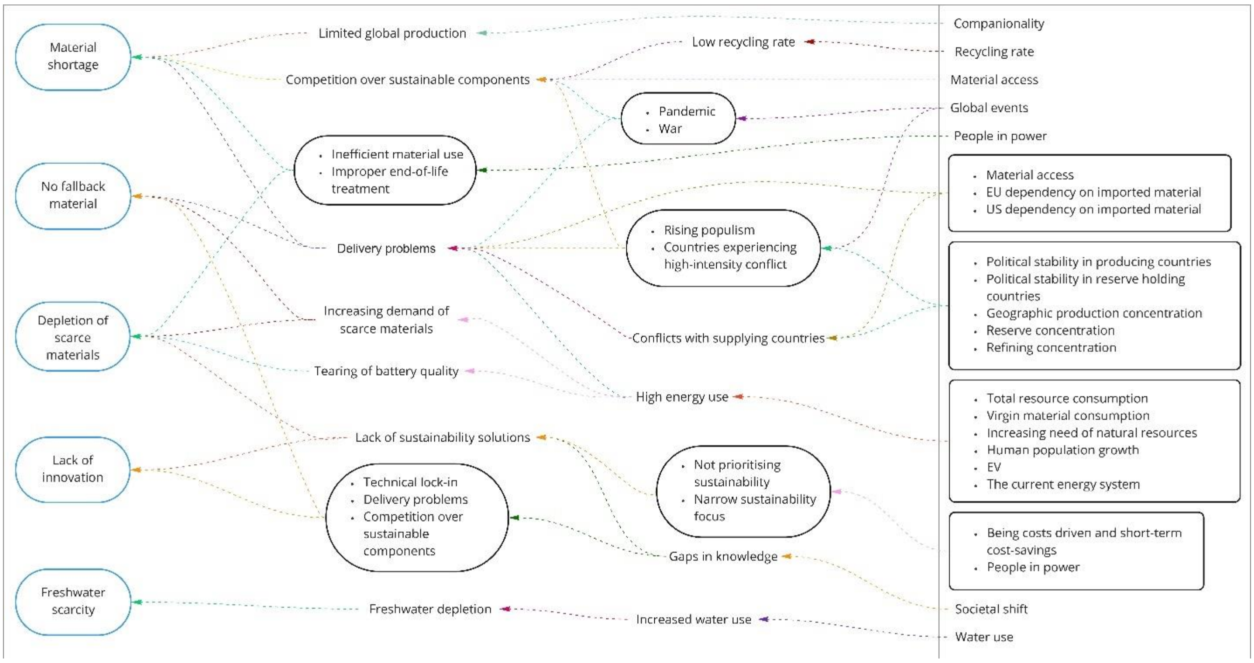


3. The Technical System

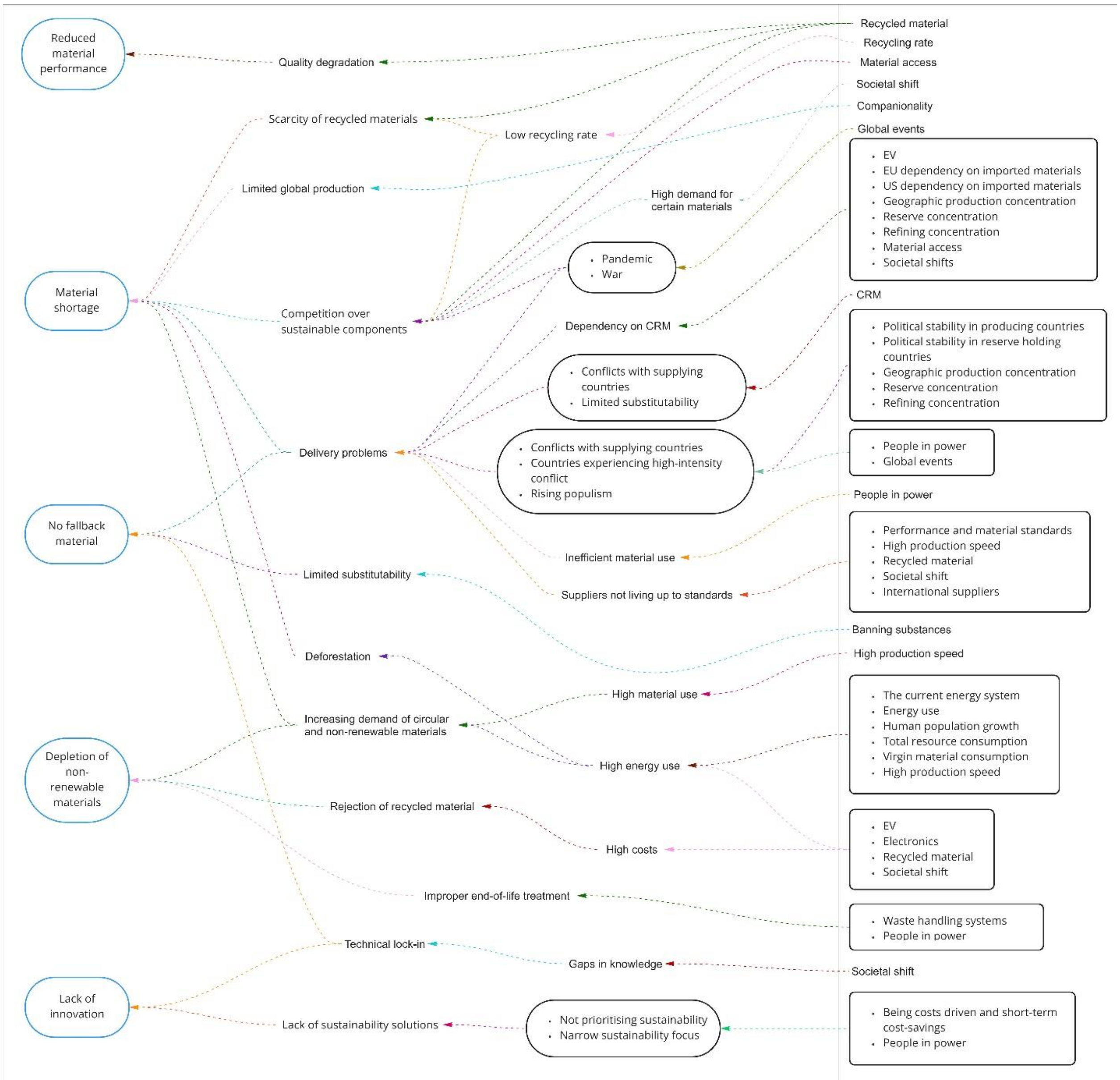
Level 1: Product – *Level 2: Product Quality*



Level 1: Materials & Supply Chain – *Level 2: Scarce Materials*

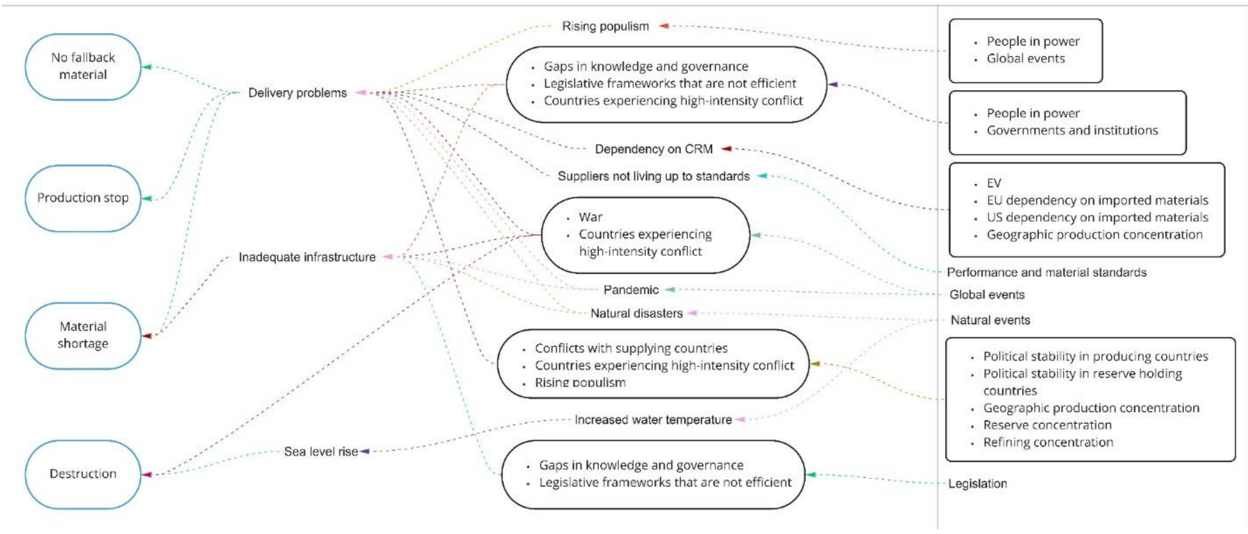


Level 1: Materials & Supply Chain – *Level 2: Circular & Non-Renewable*

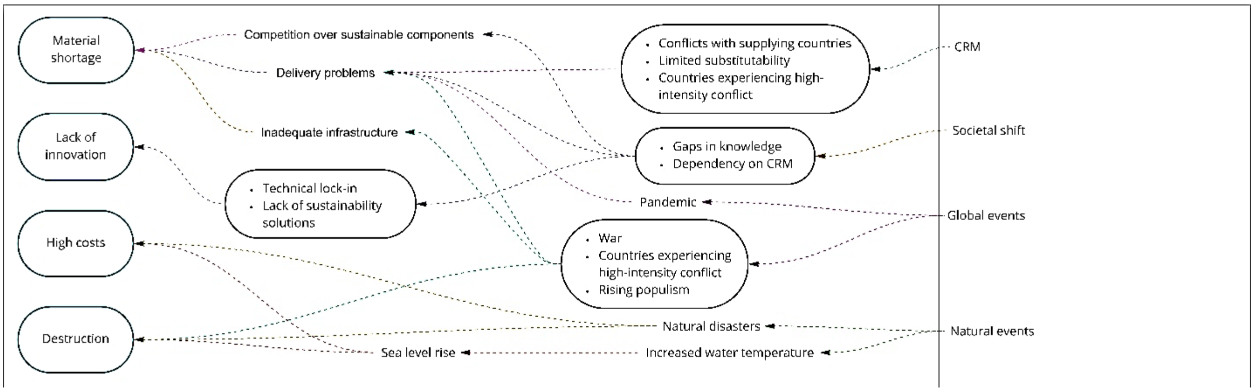


Materials

Level 1: Materials & Supply Chain – *Level 2: Extraction & Refining Processes*



Level 1: Production Facilities – *Level 2: Carbon Neutral & Renewable Energy Production Facilities*



Appendix XVI – Indicators

Below, the examples of indicators for the 15 final objects at risk are listed.

1. Indicators of the Nature System

Level 1: Climate – *Level 2: Atmosphere*

Indicator	Description	Reference(s)
Global Warming Potential (GWP)	By measuring tons CO_2-eq/tons material produced, the GWP of the material can be calculated, which measures how much energy 1 ton of emitted gas will absorb during a period of time, usually 100 yrs. Calculating the CO_2-eq enables the comparison between different GHG's. The larger the GWP, the more the gas the planet.	Baumann & Tillman (2004), EPA
Ozone Depletion Potential (ODP)	A steady-state model is used to calculate the ODP and are expressed relative to CFC-11. The World Meteorological Organisation provides an updated list of different substances' ODP.	Baumann & Tillman (2004)
Photo-oxidant Creation Potential (POCP)	The POCP of a substance is calculated by estimating the quantitative photochemical formation of ozone, and is usually expressed in ethylene equivalents.	Baumann & Tillman (2004)

Level 1: Climate – *Level 2: Ocean*

Indicator	Description	Reference(s)
Potential for acid discharge to the environment	This indicator is based on the probability of a material to be located in acidic sulfide ores, increasing the risk of acid-mine drainage and the utilisation of acid when retrieving the material. The scale for this indicator is *Yes* (Potential for acid discharge to the environment) and *No* (No/very low potential).	Drive sustainability
Ocean pollution	"Index of coastal eutrophication plastic debris density". Indicator 14.1.1 a) and b) of target 14.1 for Goal 14 *Life below water*	UN's 17 Sustainability Goals
Ocean acidification	"Average marine acidity (pH) measured at agreed suite of representative sampling stations". Indicator 14.3.1 of target 14.3 for Goal 14 *Life below water*	UN's 17 Sustainability Goals
Acidification Potential (AP)	The AP of a substance illustrates the maximum acidification it can cause. It is defined as H^+ ions produced/kg substance relative to SO_2. AP is therefore expressed in g $SO_{2\ eqv}$/g substance.	Baumann & Tillman (2004)

Marine Aquatic Ecotoxicity Potential (MAETP)	By calculating the predicted environmental concentration (PEC) and the predicted no-effect concentration (PNEC), the MAETP can be determined by using $MAETP_{substance} = (PEC/PNEC)_{Substance}/(PEC/PNEC)_{ref.substance}$ Where the reference substance is a known pesticide, 1,4-dichlorobenzene.	Baumann & Tillman (2004)
Eutrophication Potential (EP)	EP is expressed in g PO^{3-}_{4eqv}/g substance, and illustrate the maximum eutrophication the substance can cause. It is assumed that all airborne emissions of nitrogen (N) and phosphorus (P) end up in aquatic systems.	Baumann & Tillman (2004)

Level 1: Climate – *Level 2: Freshwater*

Indicator	Description	Reference(s)
Potential for acid discharge to the environment	This indicator is based on the probability of a material to be located in acidic sulfide ores, increasing the risk of acid-mine drainage and the utilisation of acid when retrieving the material. The scale for this indicator is *Yes* (Potential for acid discharge to the environment) and *No* (No/very low potential).	Drive sustainability
Freshwater Aquatic Ecotoxicity Potential (FAETP)	By calculating the predicted environmental concentration (PEC) and the predicted no-effect concentration (PNEC), the FAETP can be determined by using $FAETP_{substance} = (PEC/PNEC)_{Substance}/(PEC/PNEC)_{ref.substance}$ Where the reference substance is a known pesticide, 1,4-dichlorobenzene.	Baumann & Tillman (2004)
Acidification Potential (AP)	The AP of a substance illustrates the maximum acidification it can cause. It is defined as H^+ ions produced/kg substance relative to SO_2. AP is therefore expressed in g $SO_{2\ eqv}$/g substance.	Baumann & Tillman (2004)
Eutrophication Potential (EP)	EP is expressed in g PO^{3-}_{4eqv}/g substance, and illustrate the maximum eutrophication the substance can cause. It is assumed that all airborne emissions of nitrogen (N) and phosphorus (P) end up in aquatic systems.	Baumann & Tillman (2004)

Level 1: Climate – *Level 2: Land & Soil*

Indicator	Description	Reference(s)
Potential for acid discharge to the environment	This indicator is based on the probability of a material to be located in acidic sulfide ores, increasing the risk of acid-mine drainage and the utilisation of acid when retrieving the material.	Drive sustainability

	The scale for this indicator is *Yes* (Potential for acid discharge to the environment) and *No* (No/very low potential).	
Terrestrial Ecotoxicity Potential (TETP)	By calculating the predicted environmental concentration (PEC) and the predicted no-effect concentration (PNEC), the TETP can be determined by using $TETP_{substance} = (PEC/PNEC)_{Substance}/(PEC/PNEC)_{ref.substance}$ Where the reference substance is a known pesticide, 1,4-dichlorobenzene.	Baumann & Tillman (2004)

Level 1: Ecosystem Services – *Level 2: Biodiversity*

Indicator	Description	Reference(s)
Red List Index (RLI)	The RLI can be used when setting targets to reduce biodiversity loss, providing trends of different species' overall extinction risk. The RLI is also used as indicator 15.5.1 of target 15.5 for Goal 15 *Life on Land.*	IUCN Red List, UN's 17 Sustainability Goals
Habitat loss	"Forest area as a proportion of total land area" and "Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type". Indicator 15.1.1 and 15.1.2 of target 15.1 for Goal 15 *Life on Land*	UN's 17 Sustainability Goals
Potential for acid discharge to the environment	This indicator is based on the probability of a material to be located in acidic sulfide ores, increasing the risk of acid-mine drainage and the utilisation of acid when retrieving the material. The scale for this indicator is *Yes* (Potential for acid discharge to the environment) and *No* (No/very low potential).	Drive sustainability

Level 1: Ecosystem Services – *Level 2: Natural Resources*

Indicator	Description	Reference(s)
Estimated rate of depletion	Only applicable to mined materials. The depletion rate describes the assumed time it will take for a material to be depleted, thus, not available to mine. The availability is based on the extraction costs, technological capacity, and environmental and geopolitical factors. The estimated depletion rate is determined by evaluating a minerals unavailability in a certain number of years, counting from year 2050. The scale is divided into *Low* (>1000 yrs), *High* (100-1000 yrs), and *Very high* (<100 yrs).	Drive sustainability

Depletion of abiotic resources	This indicator is measured by using abiotic resource equivalents and based on ultimate reserves, relative to antimony (Sb).	Baumann & Tillman (2004)

2. Indicators of the Social System

Level 1: Humans – *Level 2: Workers*

Indicator	Description	Reference(s)
Child labour and forced labour	Measures the percentage of global production which is associated with child labour or forced labour. It is based on the supplying countries which the Bureau of International Labour Affairs have reason to believe are involved in these practices. It is divided into Weak, Moderate, Strong and Very Strong connections, where the percentages are: under 5%, 5% to 10%, 10% to 30%, and more than 30% of global production.	Drive sustainability
Labour rights and workers safety	"Fatal and non-fatal occupational injuries per 100,000 workers, by sex and migrant status" and "Level of national compliance with labour rights (freedom of association and collective bargaining) based on International Labour Organization (ILO) textual sources and national legislation, by sex and migrant status". Indicator 8.8.1 and 8.8.2 of target 8.8 for Goal 15 *Decent work and economic growth*	UN's 17 Sustainability Goals
Human Toxicity Potential (HTP)	By calculating the predicted daily intake (PDI) and the acceptable daily intake (ADI), the HTP for emissions to air, freshwater, and soil can be determined by using $HTP_{substance} = (PDI/ADI)_{Substance}/(PDI/ADI)_{ref.substance}$ Where the reference substance is a known pesticide, 1,4-dichlorobenzene.	Baumann & Tillman (2004)

Level 1: Humans – *Level 2: Community & Indigenous Peoples*

Indicator	Description	Reference(s)
Human Development Index (HDI)	Measures the potential human development of countries, no inequality assumed. It is a combination of three indicators; life expectancy, education, and per capita income. Countries score between 0-1, 0 representing no human development, 1 representing the highest potential human development.	Drive sustainability

Rule of Law indicator	The Worldwide Governance Indicator (WGI) has an indicator for Rule of Law, which is based on perceptions about if there is confidence in or compliance with societal rules. Especially the standard of the courts, the police, contract enforcement, property rights, and the probability of crime and violence. The Rule of Law indicator ranking lists different countries, starting with those with a strong rule of law, decreasing in strength moving down the list.	Drive sustainability
Control of Corruption indicator	The WGI has an indicator for Control of Corruption, which is based on perceptions about if public power is practiced for private gain, despite the extent of corruption. It also considers the elites' and private interests' influence on the state. The Control of Corruption ranking lists different countries, starting with those with low levels of corruption, increasing in level moving down the list.	Drive sustainability
Heidelberg conflict barometer	The Heidelberg Institute for International Conflict (HIIK) provides a conflict barometer for countries experiencing violent conflict. The levels in the barometer are *Dispute* (1), *Non-violent crisis* (2), *Violent crisis* (3), *Limited war* (4), and *War* (5).	Drive sustainability
Incidences of conflict with Indigenous Peoples	This indicator is based on the number of conflict incidences between Indigenous Peoples and producers. The conflicts include issues about land-use and resource rights, causing public grievance, protracted disputes, protests, demonstrations, and violence. In the Material Change report, this indicator is measured in terms of *Weak* (no recorded incidences), *Moderate* (1 recorded incident), *Strong* (1-3 recorded incidences), and *Very strong* (>3 recorded incidences).	Drive sustainability
Incidences of overlap with areas of conservation	This indicator is measured by only two ratings – *yes* or *no* – and indicates whether material production sites overlap with designated protected or recognised areas, with important conservation values and natural landmarks.	Drive sustainability
Potential for acid discharge to the environment	This indicator is based on the probability of a material to be located in acidic sulfide ores, increasing the risk of acid-mine drainage and the utilisation of acid when retrieving the material.	Drive sustainability

	The scale for this indicator is *Yes* (Potential for acid discharge to the environment) and *No* (No/very low potential).	
Potential for harm from hazardous materials and chemicals	An indicator for pollutants posing serious health and safety risks for both workers and communities. It is assessed by using "the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences" – the materials' and chemicals' disability adjusted life year (DALY) impact. In the Material Change report, this indicator is measured in terms of *Weak* (no recorded threats), *Moderate* (association with minor threats to health, such as dust and dermatological irritants), *Strong* (association with arsenic, cyanide and toxic heavy metals (identified as concerns by Pure Earth but not regarded as comparatively prevalent), and *Very strong* association (with lead, chromium, cadmium and mercury (identified as the highest concern by Pure Earth).	Drive sustainability
Human Toxicity Potential (HTP)	By calculating the predicted daily intake (PDI) and the acceptable daily intake (ADI), the HTP for emissions to air, freshwater, and soil can be determined by using $HTP_{substance} = (PDI/ADI)_{Substance}/(PDI/ADI)_{ref.substance}$ Where the reference substance is a known pesticide, 1,4-dichlorobenzene.	Baumann & Tillman (2004)

Level 1: Humans – *Level 2: Children*

Indicator	Description	Reference(s)
Child labour and forced labour	Measures the percentage of global production which is associated with child labour or forced labour. It is based on the supplying countries which the Bureau of International Labour Affairs have reason to believe are involved in these practices. It is divided into Weak, Moderate, Strong and Very Strong connections, where the percentages are: under 5%, 5% to 10%, 10% to 30%, and more than 30% of global production.	Drive sustainability
Human Toxicity Potential (HTP)	By calculating the predicted daily intake (PDI) and the acceptable daily intake (ADI), the HTP for emissions to air, freshwater, and soil can be determined by using	Baumann & Tillman (2004)

	$HTP_{substance} = (PDI/ADI)_{Substance} / (PDI/ADI)_{ref.substance}$ Where the reference substance is a known pesticide, 1,4-dichlorobenzene.	

Level 1: Business – *Level 2: Supply Chain*

Indicator	Description	Reference(s)
Function criticality	Measures a material's substitutability, whether a more sustainable material can be used instead without compromising the products performance or quality. A more sustainable material could be a material that is less harmful, more sustainably produced, or is more abundant. The materials are scored between 1-100, where 1 equals substitutable, and 100 means that the material can not be substituted without the performance or quality of the component being compromised. Nevertheless, a material can score differently depending on the component it is used in, or if it is assessed on its own.	Drive sustainability
Dependency – EU/US import reliance rate	The indicator measures to which degree the EU/US is dependent on important material, excluding imported recycled material. A material is scored between 0-100%, no reliance in imports – total reliance on imports. The scale can be divided into *Low* (<25%), *Moderate (25-50%), High* (50-75%), and *Very high* (>75%).	Drive sustainability

3. Indicators of the Technical System

Level 1: Product – *Level 2: Product Quality*

Indicator	Description	Reference(s)
Function criticality	Measures a material's substitutability, whether a more sustainable material can be used instead without compromising the products performance or quality. A more sustainable material could be a material that is less harmful, more sustainably produced, or is more abundant. The materials are scored between 1-100, where 1 equals substitutable, and 100 means that the material cannot be substituted without the performance or quality of the component being compromised. Nevertheless, a material can	Drive sustainability

	score differently depending on the component it is used in, or if it is assessed on its own.	
Dependency – EU/US import reliance rate	The indicator measures to which degree the EU/US is dependent on important material, excluding imported recycled material. A material is scored between 0-100%, no reliance in imports – total reliance on imports. The scale can be divided into *Low* (<25%), *Moderate (25-50%), High* (50-75%), and *Very high* (>75%).	Drive sustainability

Level 1: Materials & Supply Chain – *Level 2: Scarce Materials*

Indicator	Description	Reference(s)
Virgin material consumption	Measures the share (%) of input material in the production that is not originating from recycled material or scrap, but is rather newly mined, extracted or produced. The measuring scale is divided into *Low* (<70% virgin material, >30% recycled material), *Moderate* (70-90% virgin material), *High* (90-99% virgin material), and *Very high* (>99% virgin material, <1% recycled material).	Drive sustainability
Estimated rate of depletion	Only applicable to mined materials. The depletion rate describes the assumed time it will take for a material to be depleted, thus, not available to mine. The availability is based on the extraction costs, technological capacity, and environmental and geopolitical factors. The estimated depletion rate is determined by evaluating a minerals unavailability in a certain number of years, counting from year 2050. The scale is divided into *Low* (>1000 yrs), *High* (100-1000 yrs), and *Very high* (<100 yrs).	Drive sustainability

Level 1: Materials & Supply Chain – *Level 2: Circular & Non-Renewable Materials*

Indicator	Description	Reference(s)
Virgin material consumption	Measures the share (%) of input material in the production that is not originating from recycled material or scrap, but is rather newly mined, extracted or produced. The measuring scale is divided into *Low* (<70% virgin material, >30% recycled material), *Moderate* (70-90% virgin material), *High* (90-99% virgin material), and *Very high* (>99% virgin material, <1% recycled material).	Drive sustainability
Estimated rate of depletion	Only applicable to mined materials. The depletion rate describes the assumed time it will take for a material to be depleted, thus, not	Drive sustainability

	available to mine. The availability is based on the extraction costs, technological capacity, and environmental and geopolitical factors. The estimated depletion rate is determined by evaluating a minerals unavailability in a certain number of years, counting from year 2050. The scale is divided into *Low* (>1000 yrs), *High* (100-1000 yrs), and *Very high* (<100 yrs).	

Level 1: Materials & Supply Chain – *Level 2: Extraction & Refining Processes*

Indicator	Description	Reference(s)
Economic loss due to disasters	"Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters". Indicator 11.5.2 of target 11.5 for Goal 11 *Make cities and human settlements inclusive, safe, resilient and sustainable*.	UN's 17 Sustainability Goals

Level 1: Production Facilities – *Level 2: Carbon Neutral & Renewable Energy Production Facilities*

Indicator	Description	Reference(s)
Economic loss due to disasters	"Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters". Indicator 11.5.2 of target 11.5 for Goal 11 *Make cities and human settlements inclusive, safe, resilient and sustainable*.	UN's 17 Sustainability Goals

Appendix XVII – Contribution Report

Chapter	Author(s)
Abstract	Julia
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DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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