LAPIN AMK
Lapland University of Applied Sciences

RESILIENCE THROUGH KNOWLEDGE MANAGEMENT OF SUBSTANCES USED IN PRODUCTS

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Master's Thesis

Knowledge Management Expertise
Master of Business Administration

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Thesis abstract

Knowledge Management Expertise
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The goal was to conduct a study that supports the case company in defining the development needs of knowledge management of substances used in products. The purpose was to study how knowledge management of substances used in products could support sustainable product management and related informed decision-making in the case company. The research question asked how information related to substances and materials can support sustainable product management and how important it is for the case company. The sub-question sought to find out the important aspects of substance knowledge management for its successful development in the case company.

The thesis theory deals with the themes of sustainable product management. In addition, the theory discusses the concepts of knowledge and knowledge management, as well as substance information and its use in informed decision-making. The research method was a case study. The research data was collected by interviewing eight experts from the case company. Additionally, the interviews continued in writing and the interviewees were asked to write a letter from the future. The assignment asked to write about changes in substance knowledge management that are realistically expected to happen by the end of 2026. The research data was processed using the methods of content analysis.

The results showed that the substances used in products are one of the strategic drivers of sustainable change and business growth. Full transparency of substances enables substance knowledge management. The results highlighted the importance and complexity of substance information. Organizational commitment and a solid plan are prerequisites for successful knowledge management. The result of the thesis is a framework for substance knowledge management, which the case company can use when developing the different elements of substance knowledge management.

Keywords sustainable development, chemicals, metals, materials (matter), knowledge management

Opinnäytetyön tiivistelmä

Tiedolla johtamisen asiantuntija
Tradenomi (ylempi AMK)

Tekijä	Anne Sorjanen	**Vuosi**	2023
Ohjaaja	Milla Immonen		
Toimeksiantaja	Tietoliikennealan yhtiö		
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Sivumäärä	72 + 2		

Opinnäytetyön tavoitteena oli toteuttaa tutkimus, joka tukee toimeksiantajaa tuotteissa käytettävien materiaalien tietojohtamisen kehittämistarpeiden määrittelyssä. Tarkoituksena oli tutkia, miten tuotteissa käytettävien materiaalien tietojohtaminen voisi tukea kestävää tuotehallintaa ja siihen liittyvää tietoon perustuvaa päätöksentekoa kohdeyrityksessä. Tutkimuskysymyksenä oli, miten materiaalitieto tukee kestävää tuotehallintaa ja kuinka tärkeää se on toimeksiantajalle. Lisäksi pyrittiin selvittämään materiaalien tietojohtamisen tärkeitä näkökohtia sen onnistuneelle kehittämiselle kohdeyrityksessä.

Opinnäytetyön tietoperustassa on käsitelty kestävän tuotehallinnan teemoja. Lisäksi tietoperustassa on käsitelty tiedon ja tietojohtamisen käsitteitä sekä materiaalitietoa ja sen käyttämistä tietoon perustuvassa päätöksenteossa. Lähestymistapa tutkimukseen oli tapaustutkimus. Tutkimusaineisto kerättiin haastattelemalla kahdeksaa tapausyrityksen asiantuntijaa. Lisäksi haastattelua jatkettiin kirjallisena ja haastateltavia pyydettiin kirjoittamaan kirje tulevaisuudesta. Tehtävänannossa pyydettiin kirjoittamaan materiaalien tietojohtamisen muutoksista, joita realistisesti odotetaan tapahtuvan vuoden 2026 loppuun mennessä. Aineiston analysoinnissa hyödynnettiin sisällönanalyysia.

Tulokset osoittivat, että tuotteissa käytetyt materiaalit ovat yksi kestävän muutoksen ja liiketoiminnan kasvun strategisista ajureista ja että tuotteissa käytettyjen materiaalien täysi läpinäkyvyys mahdollistaa materiaalien tietojohtamisen. Tuloksissa korostuu materiaalitiedon merkitys ja toisaalta sen monimutkaisuus. Tietojohtamisen selkeä suunnitelma sekä organisaation sitoutuminen ovat edellytyksiä onnistuneelle materiaalien tietojohtamiselle. Opinnäytetyön tuotoksena syntyi materiaalien tietojohtamisen viitekehys, jota toimeksiantaja voi hyödyntää kehittäessään materiaalien tietojohtamisen eri elementtejä.

Avainsanat kestävä kehitys, kemikaalit, metallit, materiaalit, tietojohtaminen

CONTENTS

1 INTRODUCTION

The climate crisis is one of the greatest challenges for our planet. Climate change, environmental degradation, loss of biodiversity and natural resource scarcity are just a few of the world's existing environmental challenges (UN Environment 2019, 4). Digital technologies can help fight climate change and promote sustainability. However, they can also have negative impacts, such as increased electricity consumption, raw material consumption and emissions. (Hanski et al. 2021, 14, 58–59.)

1.1 Background

Digital technology, which is the business area of the case company, is dependent on metals, chemicals, and other elements. Electrical and electronic equipment can have a negative impact on the environment, for example because of its dependence on resource-critical materials or because it uses raw materials and processes that can have significant negative environmental impacts (Benecke, Varga & Legler 2020, 645). Furthermore, companies must manage risks in mineral supply chains, whether they are related to supply disruptions, conflicts, or environmental risks and transparency is one of the risk mitigation tools (Young, Fernandes & Wood 2019, 18, 19). The focus on reducing the negative environmental and social impact of resource use is ever-increasing, and thus the importance of knowing the materials and substances used in products continues to grow.

Knowledge does not decrease in use, but mostly increases, making it a significant resource (Adler 2002, 24). Knowledge empowers us to make informed decisions. This also applies to processes related to the environmental and supply chain management of products. Knowing the substance content of a product enables informed decision-making throughout the product's life cycle and is one component of achieving sustainable product design. However, the complexity of electrical and electronic equipment supply chains poses challenges in collecting detailed substance and material information. In addition, information must be accessible, usable, and used in order to be valuable (Laihonen et al. 2013, 44).

1.2 Objective and purpose of thesis

The purpose of this thesis is to study how knowledge management of substances used in products could support sustainable product management and related informed decision-making in the case company. This thesis aims to respond to the following research questions:

1) How can information related to substances and materials support sustainable product management and how important is it for the case company?

2) What are the important aspects of substance knowledge management for its successful development in the case company?

The goal is to conduct a study that supports the case company in defining the development needs of knowledge management of substances used in products.

It is worth mentioning that sustainable product management and related substance information management are not novel concepts. They have been strategic elements of the environmental management systems of many companies for decades and continue to be so due to a constant concern for our planet's health. In addition, companies already have practices, such as eco-design (also called Design for Environment or Sustainable Product Design), for identifying and addressing the environmental aspects of products and they are incorporated into design processes. However, with growing and topical sustainability requirements, as well as with the ever-increasing complexity and technological development of modern products, the requirements for substances used in products are increasing. In addition, the perspective of knowledge management brings added value to the case company in developing the concept of managing the substances in products.

This thesis is done as a qualitative research and the research method applied is a case study. The research is conducted by examining the literature and by interviewing subject matter experts of the case company. The interviewees are also asked to write a letter dated December 2026 to reflect their realistic expectations regarding the development of substance knowledge management in the case company. The research data is processed using content analysis.

2 SUBSTANCES AND SUSTAINABLE PRODUCT MANAGEMENT

As concerns about the environment and social aspects grow, organizations and businesses need to act in an increasingly sustainable way. Several different terms are introduced in the literature to describe concepts that promote sustainable products. Rusch, Schöggl and Baumgartner (2022, 3, 5) suggest that sustainable product management is a roof term for various concepts promoting the comprehensive sustainability management of products. They have not only included sustainable product design concepts under sustainable product management, but also a sustainable supply chain.

The focus of this thesis theory is to review how substance information can benefit sustainable product management from the point of view of the following concepts: material compliance, responsible minerals sourcing, and strategic management of product materials and substances. They can be named as important sustainability aspects also in the case company. These concepts are discussed in this chapter, and their objectives can be briefly described as follows:

1) Material compliance prevents the presence of hazardous substances harmful to people and the planet in final products.

2) Responsible minerals sourcing addresses the negative impacts of sourcing minerals, such as contributing to conflicts and human rights violations.

3) The strategic management of product materials and substances aims to, for example, secure access to raw materials or increase different sustainability aspects.

Furthermore, the literature may refer to the terms “material”, “chemical” or “substance” information. For simplification, this thesis collectively refers to these terms as “substance” information, although other terms may be used if relevant to the context.

2.1 Material compliance aims at safer products

Hazardous substances have been of interest since the 1970s and 80s when several environmental disasters related to production chemicals occurred. Soon, the material compliance of products came to the fore. Environmental compliance has developed since then, and each region can set its own requirements for products, and new regulations are constantly emerging. (Rolke, Rath & Backmann 2019, 172.)

According to Buckreus, Nuffer, Miehe and Sauer (2021, 3, 6, 8), there is no commonly used definition of material compliance. They define material compliance as the conformity of products, materials, and substances with all relevant requirements, such as laws, regulations, or customer requirements. These different requirements aim to prevent the use of hazardous substances that are harmful to the environment and people (Miehe, Mueller, Schneider, Wahren & Hornberger 2015, 289). Buckreus et al. (2021, 8) incorporate also the issue of conflict minerals, which addresses responsible sourcing of minerals instead of restricting the use of minerals, in the concept of material compliance. Due to the importance of responsible minerals sourcing for the case company, it is discussed separately in Subchapter 2.2.

The field of substance regulation is complex. Various regions and countries may have introduced their own regulations. Regulation is expected to increase further, for example because many environmental issues have not yet been addressed. Additionally, regulations are not stable, but they are subject to amendments. Such an example is the EU REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation, which is constantly updated. (Miehe et al. 2015, 289–290.)

Regulations specify restricted substances, but can also specify the application scope, substance thresholds, exclusions, exemptions, and reporting requirements for substances (Miehe et al. 2015, 289–290). Different compliance requirements may affect different elements of a material or product hierarchy, such as a substance, homogeneous material, article, component, or system. For example, the EU RoHS (Restriction of Hazardous Substances in Electrical and Electronic Equipment) defines maximum substance threshold at the level of homogeneous materials, while the EU REACH monitors substances of very high concern (SVHC) in articles, and the definitions of homogenous material and article are not the same. (Benecke et al. 2020, 647.) These potential differences in regulations must be considered in substance information. Only material producers can ensure that materials are declared correctly, since only they know the chemical composition of products. (Schenten, Führ & Lennartz 2019, 37.) The different types of substance information formats are discussed in Subchapter 4.1.

Chemical regulation continues to grow globally. However, business forces can be demanding faster and more aggressively safer materials and material transparency. This transparency includes the need for full product compositions. (Rossi 2014, 3, 6.) Detailed substance information on products improves the possibilities for substitution of hazardous substances and enables informed choices across the product value chain. In addition to managing detailed information on substances in companies, the exchange of knowledge between companies, government authorities and the research world is one of the fore-front efforts on managing the compliance of substances. (KEMI 2016, 14–17.)

2.2 Responsible minerals sourcing

Mining involves potential social and environmental risks, such as contributing conflict, human rights violations, or environmental destruction (van den Brink, Kleijn, Tukker & Huisman 2019, 389–390) and raw materials used in electronics may originate from such connections (Hanski et al. 2021, 41). For example, the Democratic Republic of Congo (DRC) is known for its conflicts and is one of the main producers of tantalum and cobalt (Hanski et al. 2021, 41).

However, conflict-affected countries may be economically dependent on mining and its closure may have negative social consequences. Therefore, measures should mitigate the negative effects of mineral production and not just prohibit supply from these regions. In addition, for example, the EU is dependent on the production of certain raw materials in conflict-affected countries, such as the mentioned DRC. (Hanski et al. 2021, 42.)

Responsible minerals sourcing addresses the negative impacts of mineral sourcing, and this can be done through a combination of actions, such as policies, making positive contributions in mines, or due diligence (GRI & the RMI 2019, 7). According to the definition by the OECD (2016, 13), “due diligence is an on-going, proactive and reactive process through which companies can ensure that they respect human rights and do not contribute to conflict."

Various instruments have been developed to support responsible sourcing of minerals. In 2010, the United States passed Section 1502 of the Dodd-Frank Act to address concerns about conflict minerals (tin, tantalum, tungsten, and gold, abbreviated 3TGs) in the DRC region (SEC 2017), and it affects worldwide through global mineral supply chains (Franken & Schütte 2022, 657). It requires the companies affected to disclose whether they use conflict minerals and whether these minerals originate in the DRC or an adjoining country (SEC 2017). The EU has also passed its own regulation. It came into force in 2021 and affects EU importers of minerals. (EU 2021.) Another tool is the OECD Due Diligence Guidance, which is a leading guideline for companies looking to source their minerals responsibly (van den Brink et al. 2019, 392). It is voluntary, but since it has been applied by the US Dodd-Frank Act and EU regulation, it has become the industry standard for conflict minerals (Franken & Schütte 2022, 657). Furthermore, another widely utilized resource for companies to address responsible minerals sourcing is the Responsible Minerals Initiative (RMI), founded in 2008 (RMI 2023a). The RMI programme complies with the OECD Guidance and both regulations (RMI 2023c).

One of the practical measures developed to avoid the use of minerals from conflict sources is tracing the origin of a mineral back to its producer mine and country (Hanski et al. 2021, 42). This supply chain mapping plays an important role in the due diligence process (van den Brink et al. 2019, 392), and the OECD defines smelters and refiners as a control point in mineral supply chains (Young et al. 2019, 6). The tools and resources provided by the RMI help identify smelters in companies' supply chain, enabling companies to make informed sourcing decisions (RMI 2023c).

Responsible minerals sourcing has expanded beyond conflict minerals (3TGs) (van den Brink et al. 2019, 396; Franken & Schütte 2022, 666). The original scope, the so-called "conflict minerals", issued in the early 2000s when violence and human rights abuses continued in the eastern DRC after the Congolese war, and the mining of conflict minerals used in electronics and cars was associated with this ongoing conflict (van den Brink et al. 2019, 389). The third edition of the OECD Due Diligence Guidance has been updated to provide a framework for detailed due diligence to ensure responsible supply chain management of all minerals, not only 3TGs (OECD 2016, 4). In addition, the RMI has expanded its tools to cover other minerals (RMI 2023b).

The regional scope has also changed. The DRC and nine adjoining countries are the original scope of conflict minerals (SEC 2017). The OECD has expanded the scope of conflict areas later and uses the term “conflict-affected and high-risk areas” (CAHRA). CAHRA refers to areas where there is a likelihood of causing serious physical harm to people or other human rights violations, such as forced or child labor. (OECD 2016, 13, 19–20.)

Growing requirements also increase the need for companies to better understand the minerals used in their products. Responsible and transparent sourcing has become an expectation for material producers and users (Young et al. 2019, 18). Franken and Schütte (2022, 654) state that mineral sourcing increasingly involves industry or multi-stakeholder initiatives, and that the expansion of these voluntary initiatives also anticipates the development of public and regulatory bodies.

2.3 Strategic management of product materials and substances

Digital technology consumes a wide variety of minerals and metals. It has a particularly high proportion of the consumption of elements such as copper, gallium, germanium, gold, indium, platinum-group metals, rare earth elements and tantalum. (Hanski et al. 2021, 23.) The reliable availability of certain raw materials is a growing concern all over the world. Different regions have developed their own policies that affect the value chain of raw materials, but companies may also have their own strategies and priorities.

2.3.1 Critical and strategic raw materials

To address the challenge of raw material access, different regions have identified critical raw materials (CRMs) that are economically critical and carry supply risks (Charles, Douglas, Dowling, Liversage & Davies 2020, 2). The availability of

CRMs is not always a question of the scarcity of geological resources but about an access to the supply of raw materials (Kalaitzi, Matopoulos, Bourlakis & Tate 2018, 784; Charles et al. 2020, 2). The production of CRMs is concentrated in a small number of countries, and many of them have their own needs for resource consumption (Charles et al. 2020, 2). Additionally, resource competition and geopolitical tensions may increase the risk of supply disruptions (European Commission 2023c). For example, China dominates the market of rare earth elements and impacts their price and availability (Kalaitzi et al. 2018, 784).

The EU has maintained its list of CRMs since 2011. It is part of the European Green Deal, which is a package of policy initiatives transforming the EU into a modern, resource-efficient, and competitive economy (European Commission 2023b). The EU Commission's proposal for a regulation called the EU Critical Raw Materials Act was released in March 2023. It aims to ensure an adequate and diversified supply for Europe's digital economy and green transition by prioritizing re-use and recycling. (European Parliament 2023.)

The proposed regulation introduces strategic raw materials (SRMs), which is a sub-group of CRMs. SRMs include CRMs that are strategically important for green, digital, space and defense applications. The proposed regulation includes a requirement for large companies manufacturing strategic technologies containing SRMs in the EU to audit their supply chain every two years, including, for example, a mapping of where the SRMs they use are extracted, processed, or recycled. The objective is that companies consider the supply risks of SRMs and develop mitigation strategies to prepare for supply disruptions. (European Commission 2023c.)

While different regions are strengthening their policies around CRMs and SRMs, companies may also have their own strategies for prioritizing the management of different substances. Kalaitzi et al. (2018, 800) suggest that companies need to explore where scarce natural resources are used in their products and evaluate the implications of material scarcity risk on a successful supply chain strategy. They also highlight early involvement in the product design process. Gaustad, Krystofik, Bustamante and Badami (2018) have a broader view. They (2018, 27–28, 31) stress that companies have a clear need to develop their own strategies and priorities to address the risk levels of raw materials. The risk may be related to, for example, material shortages, material substitutability, price volatility, world supply, as well as sourcing and geopolitical risks.

2.3.2 Circular economy

The European Green Deal also includes the concept of a circular economy, which can be linked to critical raw materials, among other things. Promoting the circular economy helps in achieving the objectives of CRMs, and a key mitigation solution is to increase the recycling of CRMs and the reuse of components containing CRMs (Koppelaar et al. 2023, 2).

To get the whole picture, it is worth mentioning that the circular economy also has other goals. The European Commission (2020b) defines the circular economy as follows: "In a circular economy, the value of products, materials and resources is maintained in the economy for as long as possible, while waste generation is minimised." According to the outlook by the OECD, the use of materials, such as metallic ores, would double by 2060 without policies addressing material efficiency. The extraction, processing and disposal of materials have negative environmental impacts, such as greenhouse gas emissions and pollution to the soil, water, and air. (OECD 2019, 3.) Furthermore, constant consumption increases the amount of waste. The waste stream of electrical and electronics products is one of the fastest growing waste streams in the world (Rizos et al. 2021, 7).

Hsu, Domenech and McDowall (2022, 950) stress that the circular economy requires different operators to have access to data, information, and knowledge throughout the entire value chain, making it more data- and knowledge-intensive than the linear economy. In order to keep products and materials in the economy, sufficient information about products is necessary (Jäger-Roschko & Petersen 2022, 1). Information about the material composition of products helps that materials can be properly sorted and processed (UNEP 2015, 14). Material information is one factor that helps reduce dismantling costs and improve the quality of recycled materials (Adisorn, Tholen & Götz 2021, 11).

In addition to CRMs, the literature suggests that there are two types of valuable information for recyclers: hazardous substances and valuable materials

(Scruggs, Nimpuno & Moore 2016, 157; Jäger-Roschko & Petersen 2022, 6; Saari et al. 2022, 16). Valuable materials include precious metals with high economic value, such as silver, gold, and platinum group metals (Bakas et al. 2016, 27), or rare metals (Scruggs et al. 2016, 156). Although there are challenges in recycling critical metals, it can be profitable, for example, because the concentrations of metals in finished products can be much higher than in natural ores (Bakas et al. 2016, 28). Information on hazardous substances helps recyclers to handle and dispose of products safely (Scruggs et al. 2016, 157), as well as it enables the generation of better-defined secondary materials (European Commission 2020a, 12; Jäger-Roschko & Petersen 2022, 12). Rizos et al. (2021, 24) state that limited information of substances used in electronic devices can be a barrier to the circular economy.

In addition to reducing material shortages and waste, the use of recycled materials in products can significantly reduce negative environmental impacts, such as energy consumption or CO2 emissions. The footprint of primary materials may even increase in the future due to lower-grade ore deposits. (Hanski et al. 2021, 51, 64.) Additionally, the use of materials suitable for recycling can further support sustainability (Benecke et al. 2020, 646).

A digital product passport is one tool to address information gaps in product materials. The proposed EU Ecodesign for Sustainable Products Regulation sets a wide range of performance and information requirements for almost all categories of goods placed on the EU market (European Commission 2023a). It introduces a framework for a Digital Product Passport (DPP). The DPP manages information related to the environmental sustainability of products, such as recycled content, and aims to improve the transparency of the environmental impacts of products (European Commission 2023a). The DPP may include information on chemicals, materials, and components (Saari et al. 2023, 3). However, the concept of the DPP is under construction (Saari et al. 2023, 2) and it is expected that digitalization, such as IoT, blockchain or machine learning, will aid to implement data collection (Adisorn et al. 2021, 9).

However, taking into account various aspects of the circularity of products is not a novel concept, but its objectives have been considered both in design processes and in the field of regulation and are already being implemented. For example, Article 15 of the WEEE Directive 2012/19/EU requires producers to provide information on substances requiring special handling at end-of-life (Benecke et al. 2020, 650), and the Waste Framework Directive requires a notification of articles containing Substances of Very High Concern (SVHCs) in concentrations above 0.1 % by weight to the SCIP (Substances of Concern In articles as such or in complex objects (Products)) database by the European Chemicals Agency (European Commission 2020a, 24; Adisorn et al. 2021, 5–6). The aim of the SCIP database is to provide waste operators with information on SVHCs to ensure high-quality recycling (Adisorn et al. 2021, 6; ECHA 2021b), as well as to enable consumers to make informed decisions about the presence of hazardous substances (ECHA 2021a).

3 CREATION AND USE OF KNOWLEDGE

Knowledge management has taken its place in the success of companies. Knowledge enables informed decision-making and creates value for a company. Knowledge can be considered as a significant resource (Adler 2002, 24). Knowledge management aims to improve organizational performance, and the choice of knowledge management activities must be based on the objectives of an organization (Laihonen et al. 2013, 79–80). This chapter introduces the principles of knowledge and knowledge management.

3.1 Forms of knowledge

Knowledge is a broad concept, and it has many definitions and classifications in the literature. Rowley (2007, 163–164) states that the data-information-knowledge-wisdom (DIKW) hierarchy is a widely recognized model. It demonstrates the hierarchical relationship between data, information, knowledge, and wisdom, and the transformation process of the different layers of the model while moving up the hierarchy. The lower layer is needed to create the next layer. (Rowley 2007, 164.)

Each level of the hierarchy is a step towards a higher level of understanding and each level adds value to the initial data. Rowley (2007, 166) summarizes the definitions by Ackoff as follows:

1) Data are symbols for the properties of objects and events.
2) Information answers the questions: who, what, when, where and how many. It is processed data.
3) Knowledge is know-how and can be obtained by amending information by instruction, by getting from another who has it, or by using experience.
4) Wisdom increases effectiveness.

Rowley (2007, 174) adds that knowledge can be a mix of information, understanding, capability, experience, skills, and values. Käpylä and Salonius (2013, 13) emphasize the meaning of interpretation in the context of knowledge. Liew

(2013) argues that wisdom is the understanding of universal truth, sound judgement, and appropriate execution. Bratianu and Bejinaru (2023, 202) elaborate that wisdom deals with a future that is uncertain. People's ability to deal with uncertainty can be different, and that makes the difference between their level of wisdom. The evaluation of wisdom can only be done after seeing the consequences. (Bratianu & Bejinaru 2023, 202.) Liew (2013) suggests that intelligence is lacking from the DIKW model. He places it between knowledge and wisdom, where it plays an important role. He defines intelligence as mental thinking capacities, such as learning, problem solving, as well as analytical, critical, creative, and quick thinking.

The DIKW hierarchy can be used to link information systems hierarchies, helping define the roles of different information systems. (Rowley 2007, 175–176.) Figure 1 demonstrates the DIKW hierarchy and corresponding information systems.

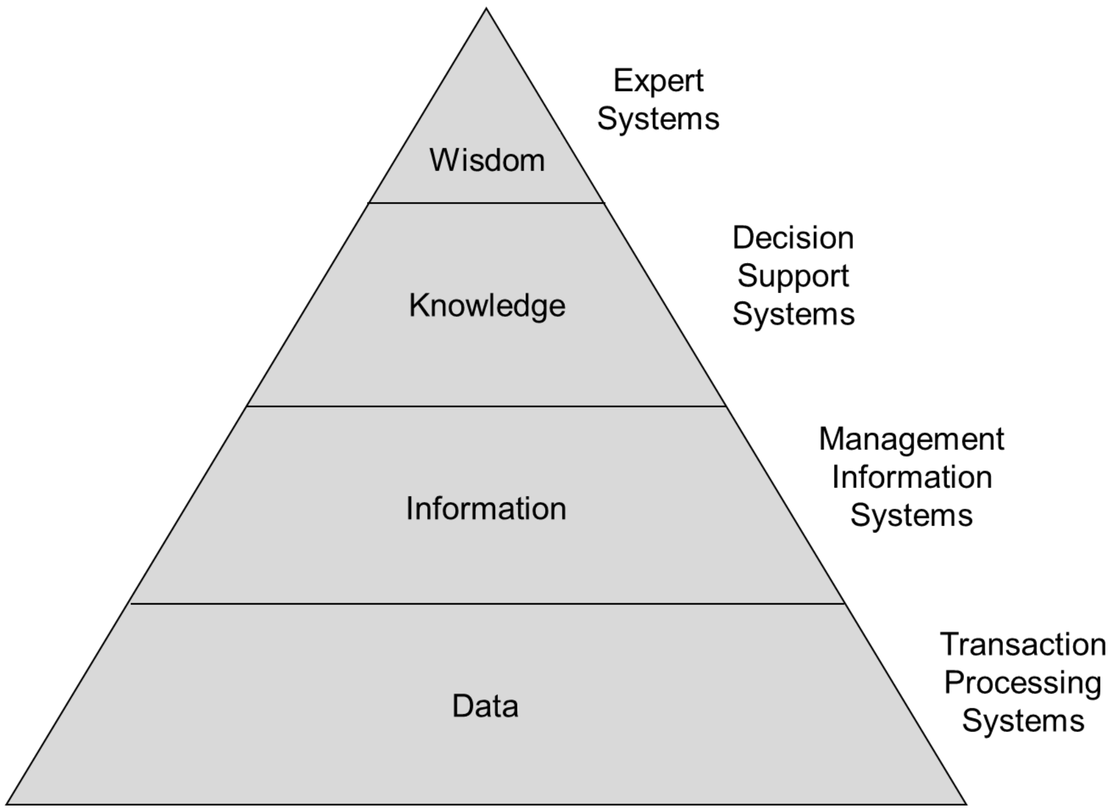

Figure 1. DIKW hierarchy and corresponding information systems (adapted from Rowley 2007, 176)

Knowledge can be also classified between explicit and tacit knowledge. Explicit knowledge is in written form and can be shared easily. Tacit knowledge is gained from personal experience, and it can be also unconscious. Sharing tacit knowledge can be difficult. Data and information can be clustered as explicit, and most knowledge is tacit. Knowledge management aims that also knowledge can be shared in an explicit form. Tacit knowledge should be used because it fosters innovation and efficiency. In addition, an organization benefits if tacit knowledge is transferred to an explicit form because it helps to keep the knowledge in the organization. (Laihonen et al. 2013, 18–19, 57–58.)

Knowledge is a constantly changing resource. Knowledge creation can be described with the SECI model by Nonaka and Takeuchi. The SECI model emphasizes that also tacit knowledge must be used by an organization. (Laihonen et al. 2013, 56–57.) It is an interactive process of four steps in which tacit knowledge and explicit knowledge alternate (Käpylä & Salonius 2013, 56) and this continuous process increases the knowledge of an organization (Laihonen et al. 2013, 57).

Nonaka and Takeuchi (2007, 164) summarize that the creation of knowledge is a way of behaving and a way of being. Rowley (2000, 8) suggests the concept of a knowledge entrepreneur. She defines that such an organization optimizes and capitalizes its knowledge resources in pursuit of its vision by interfacing organizational learning and systems evolution. The readiness and motivation of people participating in the process are key prerequisites for the success of the knowledge creation process. Additionally, the diverse knowledge base of people involved will more likely generate new knowledge. (Käpylä & Salonius 2013, 58–59.)

3.2 Knowledge management

Knowledge is an asset that can create value. However, a challenge is to understand how value can be created. Knowledge management offers models and tools for adopting knowledge in the daily operations of organizations. (Laihonen et al. 2013, 8, 11, 24, 31.) It is about creating value with information, knowledge, and expertise (Finto 2018b). The success of knowledge management depends on people's ability to maintain and share their experiences and search for new information in order to develop, so all employees are responsible for knowledge management. Thus, knowledge management is also about managing people. (Laihonen et al. 2013, 12, 80.)

Knowledge management is a roof term for information management and knowledge-based management (Käpylä & Salonius 2013, 7; Finto 2018b). The concept is summarized in Figure 2.

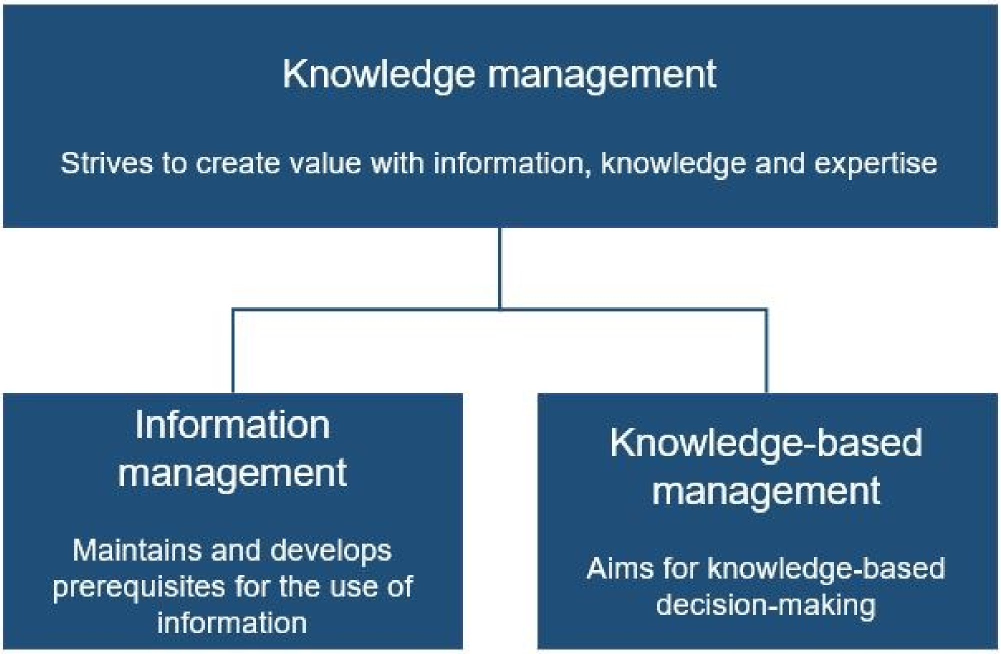

Figure 2. The concept of knowledge management (adapted from Finto 2018b)

Information management is a prerequisite for knowledge-based management (Finto 2018a). It involves the creation of new information and the management of information sharing, learning, renewal, and information flows (Käpylä & Salonius 2013, 7) with an emphasis on information systems (Leskelä et al. 2019, 15). Knowledge-based management supports informed decision-making (Käpylä & Salonius 2013, 7). It can be described simply as using information (Kosonen 2019).

Knowledge must have an impact on decision-making to be valuable. It must be interpreted correctly, and it must be in the right person at the right time and in a usable form. Informed decisions guide an organization and help it to succeed. (Laihonen et al. 2013, 44.) Likewise, Rowley (2000, 7) continues that knowledge is relevant when it contributes to the completion of a task, such as decision-making, problem-solving, or learning, and meets the requirements of a user. Timeliness, accuracy, and in particular, the level of detail and completeness of knowledge are factors that help assess relevance. Additionally, outdated knowledge needs to be weeded out. (Rowley 2000, 7.)

The literature presents many process models that support knowledge management. According to Evans, Dalkir and Bidian (2014, 98) the knowledge management process can be started for many reasons, such as strategic or operational problem solving, decision-making, knowledge gap analysis, or innovation. Based on the literature, they (2014, 98) have compiled seven steps of the knowledge management process: identify, create, store, share, use, learn, and improve and are emphasizing that the process of knowledge creation is iterative. The steps are described in Figure 3.

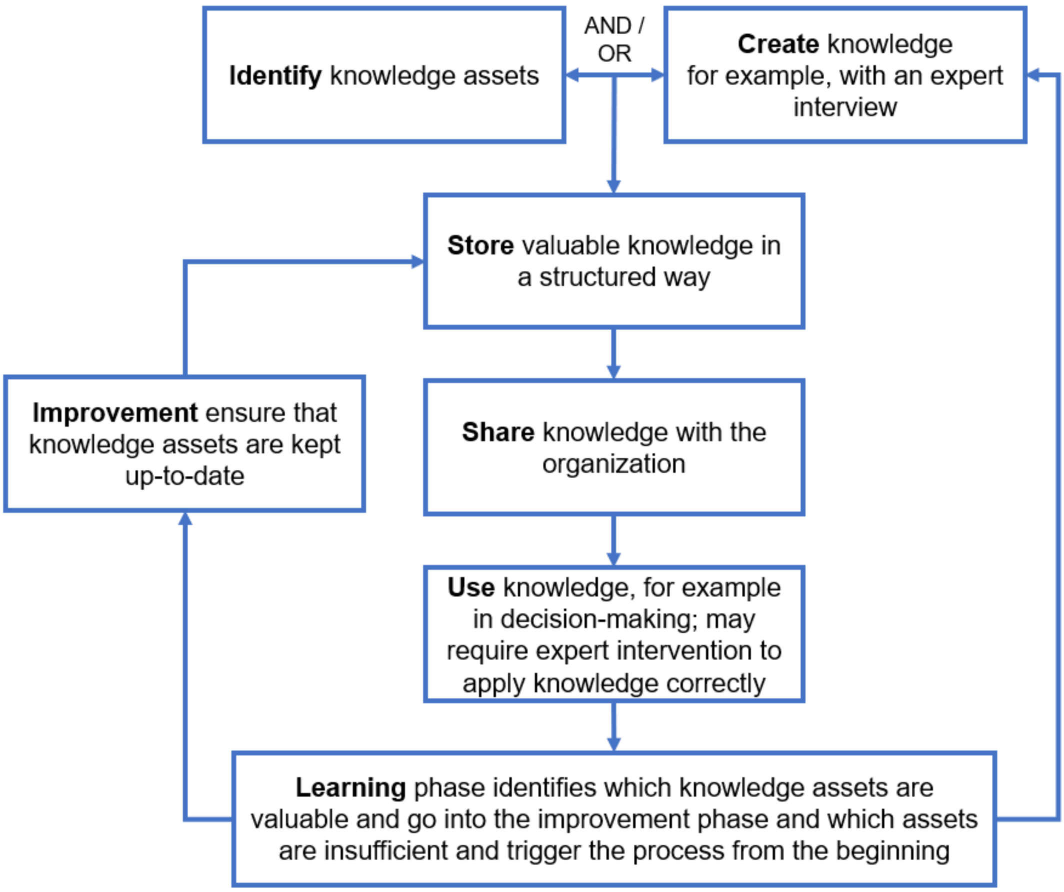

Figure 3. The process of knowledge management (adapted from Evans et al. 2014, 98–100)

Burkhard (2014) lists the following difficulties that must be solved in order to transfer knowledge:

1) Level of knowledge details to be shared (information depth),

2) Time constraints for knowledge recipients,

3) Cognitive differences of knowledge recipients, and

4) Providing relevant information to different stakeholders.

Knowledge visualization increases the transferability of knowledge. Visualization can even create knowledge. (Troise 2022, 1125.) It also increases effectiveness and consumes less energy (Burkhard 2014).

4 SUBSTANCE INFORMATION AND USING IT IN DECISION-MAKING

According to Hsu et al. (2022, 944), data, information, and knowledge play a central role in the transformation of socio-technical systems. Rusch et al. (2022, 3) emphasize that a closed loop of product and material information is essential for implementing sustainable product management. Furthermore, an environmentally visionist company applies a long-term vision and actively spreads knowledge throughout the company and value chain, thus having a positive impact on the company's stakeholders (Salo, Suikkanen & Nissinen 2020, 2656). Young et al. (2019, 17) emphasize the position of original equipment manufacturers in the supply chain, stating that they play a significant role there by influencing lower-tier suppliers in their sustainable practices.

In this thesis, substance information is linked to the DIKW hierarchy, which is visualized in Figure 4, as follows:

1) Data is a detail, like the name of a substance, which does not provide any intelligible information.

2) When the name of a substance is contextualized, for example to a part, it turns to information. Substance information is processed data and describes, for example, a product composition or compliance statement in relation to the defined list of substances. The value of this information can be further improved, for example, by classifying substances or by linking them to regulations, which allows for an even higher level of understanding. The information can be further analyzed, measured, and visualized for a specific purpose.

3) Knowledge is an understanding of how to interpret and apply substance information to achieve goals. An expert can create knowledge, for example, through experience or exchanging knowledge with others. For example, two of the company's products get different results for CO2 calculations. An expert realizes through other knowledge that it can be because of some materials chosen and is able to study the product compositions to find the reason why another product has a greater impact.

4) Wisdom adds effectiveness in managing substances and can deal with the future. For example, an expert estimates that a certain group of chemicals will be regulated in the future and starts driving the phase out of them in the company's products. The expert can pass this on to the design teams of the company, who take it into account when designing products, so that new products consider this future regulation and no separate design changes are required.

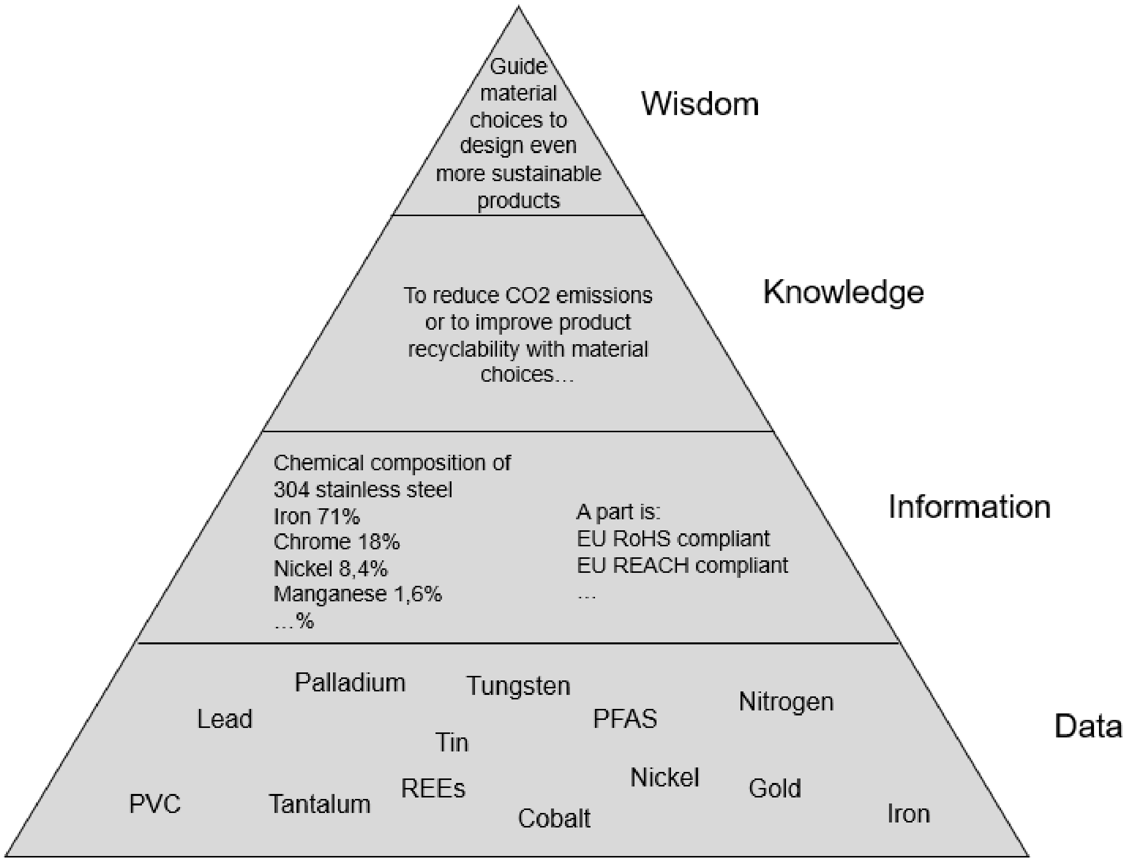

Figure 4. DIKW (adapted from Rowley 2007, 176) and substance information

This chapter explains the formats for reporting substance information and how informed decision-making helps create sustainable products. Also, the topic of substance information management systems is touched upon, but it is not the focus of this thesis.

4.1 Substance information reporting formats

There is no single standard that defines substance information management (Schenten et al. 2019, 36), and strategies for managing substance information vary greatly between companies (Rossi 2014, 2). Substance management strategies can be described as passive or active. A passive strategy ensures compliance with regulations, while an active strategy integrates the knowledge of the chemical content of products into company management systems, such as product design, material selection, and supplier engagement. (Rossi 2014, 2–4.) These different goals by companies have led to the introduction of various substance information exchange processes, tools, and formats.

There are two main methods of exchanging information on substances: restricted substance list (RSL) based declarations and full material declarations (FMD) (van Meensel, Willems & Cauwe 2014; UNEP 2015, 16–17; Schenten et al. 2019, 35–36). The RSL declaration can be connected to a passive strategy, while FMD management is an active strategy. RSL declarations are simple yes/no declarations against an RSL of interest, such as a regulation or a company's own list for addressing substances of concern (UNEP 2015, 16). The FMD is a comprehensive list of substances present in products, including substance concentrations (van Meensel et al. 2014).

In addition to the information exchange methods, there are many information exchange formats for reporting substance information by companies. Different sectors may have adopted different information exchange standards, and a sector may have adopted many standards (Proactive Alliance 2021, 10–11, 21). In addition, companies can have their own custom templates for exchanging information (Scruggs et al. 2016, 160; Theret & Blaszkowski 2020, 749). In the electronics and electrical sector, two material declaration standards are used, IPC-1752 and IEC 62474 (Rolke et al. 2019, 174; Theret & Blaszkowski 2020, 750; Proactive Alliance 2021, 21) while IPC-1752 is the most widely applied standard (Proactive Alliance 2021, 22). These standards have been converging and both standards include four different classes of declarations that can support RSL declarations or FMDs (Proactive Alliance 2021, 22, 25–26).

The Proactive Alliance, which is an inter-section group, is seeking a solution for cross-sectional collaboration and standardization of substance information exchange (Rolke et al. 2019, 176). It aims to achieve interoperability between existing standards and that all standards are compatible with an FMD, but also supports list-based declarations for meeting regulatory obligations (Proactive Alliance 2021, 11).

The RSL declarations can only comply with substances listed up to the date of declaration, which means that each new addition to substance restrictions makes the declaration obsolete, which is not cost effective (Rolke et al. 2019, 174, 176; Schenten et al. 2019, 35, 38). Repeated inquiries about RSL declarations can irritate suppliers (Rolke et al. 2019, 176). Moreover, the RSL declaration is not optimal for recyclers, as its timeliness in relation to current restrictions may be uncertain (Schenten et al. 2019, 35–36). However, the RSL declaration is a simple and straightforward method to ensure that a product is compliant with regulatory requirements (UNEP 2015, 16).

An FMD at a homogenous material level, including the weight of each substance in that level, is the most detailed information (van Meensel et al. 2014). The term of homogenous material is defined in the EU RoHS (Restriction of Hazardous Substances) Directive (Schenten et al. 2019, 37). The definition of “homogenous material” differs from the definition of “article” by REACH Art. 3(3), which must be considered in the FMD. The main material declaration standards IPC-1752 (IPC 2022) and IEC 62474 (IEC 62474 2020) both include the different material level requirements of the EU RoHS and EU REACH, as well as exemptions defined by the EU RoHS.

Schenten et al. (2019, 36) state that an FMD-based approach is a prerequisite for achieving manageability for the proper identification and control of substances in a company's products. With the FMD-based approach companies can meet the current requirements of legislation, industry or companies and prepare for future regulations and requirements, such as the circular economy (Schenten et al. 2019, 32, 38). For example, FMDs allow material changes as planned when a new regulation is introduced (UNEP 2015, 17). Transparency of chemical information helps to reduce the cost of creating products that do not contain hazardous chemicals and allows companies to anticipate business risks and opportunities (Scruggs et al. 2016, 157). FMDs increase also better control of product quality and liability risks (Rossi 2014, 11, 23; Schenten et al. 2019, 38).

Rolke et al. (2019, 176) argue that the FMD approach is in the best interest of most operators in the industry. Rossi (2014, 3–4) states that proactive companies do not wait for regulations or product recalls, but they combine knowledge of the materials in products and supply chains into their management systems and create value for the company. In addition, brand owners play a significant role in improving substance information management because they are involved in the entire value chain (Scruggs et al. 2016, 162).

However, managing FMDs can be overwhelming and expensive (Scruggs et al. 2016, 155), although the cost of managing them levels out over time (Rossi 2014, 22). Moreover, information is only useful when it can be verified as accurate and adequate. FMDs can be incomplete due to a lack of understanding, suppliers just do not have the information requested, or the supply chain is unwilling to disclose all information due to concerns about the confidentiality of proprietary substances (Scruggs et al. 2016, 155). Table 1 summarizes the main advantages and disadvantages of the RSL declarations and FMDs.

Table 1. The main methods of substance information exchange and their advantages and disadvantages

Method	Advantages	Disadvantages
Restricted substance list –based declaration	Simple and straightforward method to ensure regulatory compliance (UNEP 2015, 16)	Changes in regulation makes the declaration obsolete (Rolke et al. 2019, 174; Schenten et al. 2019, 35) Not cost effective due to repeated inquiries (Rolke et al. 2019, 176; Schenten et al. 2019, 38)
Full material declaration	Enables compliance with current and future requirements of legislation, industry, or companies (Schenten et al. 2019, 32, 38) Allows material changes as planned when new regulation is introduced (UNEP 2015, 17) Allows to anticipate business risks and opportunities (Scruggs et al. 2016, 157) Cost levels out over time (Rossi 2014, 22)	Managing can be overwhelming and expensive (Scruggs et al. 2016, 155) Problems with the accuracy and completeness of information (Scruggs et al. 2016, 155)

4.2 Informed decision-making for driving sustainability

Making informed choices in product design is crucial to promoting sustainability. The design process plays an important role, as the choices made during the design phase determine resource consumption throughout the product's lifecycle (Buchert et al. 2019, 1051). It has been estimated that up to 80% of the environmental impacts of a product's entire life cycle are determined as a result of product design (Hanski et al. 2021, 59). The view of Hallstedt, Isaksson, Watz, Mallalieu and Schulte (2022) supports this, and they emphasize that early integration of sustainability aspects to guide decision-making is essential.

Various methods and software tools, such as Life Cycle Assessment, have been developed to help decision-making in product development processes. However, there are shortcomings in how they are integrated into product development to support decision-making. (Buchert et al. 2019, 1051–1052.) This thesis does not explain the details of existing decision-making tools but seeks to identify key knowledge management aspects of how substance information can be taken into account in the substance knowledge management process.

The development of sustainable products can be seen as a multi-criterial decision problem, and relevant information supports informed decision-making (Buchert et al. 2019, 1061). An environmentally mature company uses more accurate ecodesign tools (Salo et al. 2020, 2656). Appropriate knowledge management is necessary to reduce the effort needed for the acquisition of sustainability information. Such knowledge management can include processes, IT tools, and central data repositories. (Stark, Buchert, Neugebauer, Bonvoisin & Finkbeiner 2017, 27.) Diaz, Schöggl, Reyes and Baumgartner (2021, 1040–1041) suggest that the sources of information can be structured or unstructured and can include suppliers, internal expertise, past projects, and sources of generic data, such as lifecycle analysis (LCA) software. Material declarations are part of knowledge required for sustainable product development (Brambila-Macias & Sakao 2021, 6).

Sharing existing information, identifying information gaps, and collaboration on information management between environmental compliance and design teams maximize the benefits of environmental information, including substance information (Benecke et al. 2020, 649–650). In addition, knowledge needs to be transferred to an explicit form, such as guidelines, to ensure knowledge sharing between the different actors in the supply chain of companies (Hsu et al. 2022, 949). However, the process of analyzing sustainability must not be complicated, and different indicators can be used for different product categories to optimize the most relevant sustainability measures (Stark et al. 2017, 27). Visualization and highlighting priorities further support decision-making (Buchert et al. 2019, 1061).

However, Brambila-Macias and Sakao (2021, 6) highlight that knowledge of materials can be quite specific and often requires the support of a materials expert.

Buchert et al. (2019, 1054–1055, 1060) suggest that a product data management (PDM) system shall have a function that collects relevant information from previous designs and guides design choices to improve resource efficiency with selected indicators. They continue that the advanced solution also provides design alternatives based on existing designs with the help of artificial intelligence.

Hornberger, Miehe and Bauernhansl (2014, 141–146) propose a hazardous materials management system to meet environmental compliance. It consists of five main categories with different subtasks that control the materials management system. The subtasks include defining targets guided by external requirements, assessing the state of the company and risk level according to the defined material and supplier risk, corrective actions for identified risks, continuous development, and improvement of the management system.

Rossi, Papetti, Marconi and Germani (2019, 377–381) introduce the Product Impact Index (PII), which is a multi-criteria analysis to assess the environmental, economic, and technical performance of products. The tool supports the effective implementation of eco-design and making informed choices, but also helps to create knowledge in a structured way. The tool has the following main stages: 1) identification and prioritization of company objectives, 2) analysis of a product using the tool, 3) redesign of the product if criticalities are identified, and 4) definition of a long-term strategy based on the lessons learned in the previous stages.

In summary, based on the literature, making informed decisions regarding materials is important to promote sustainability. Relevant tools, such as design tools, should support decision-making on material choices and make the design choices related to materials easy. Designers are not necessarily the experts of complex ESG (Environmental, Social and Governance) aspects, and guiding the material choices through the tool would increase the sustainability of products.

4.3 Substance information management systems

The focus of this study is not to define substance information management systems, but since systematic knowledge management is supported by systems and databases, it is essential to explain this connection. This also supports the case company in defining substance information management in more detail as an extension of the thesis.

A company's IT structure must support compliance processes. Proper IT integration is essential for compliance, and stakeholders' timely access to accurate information must be ensured. (Miehe et al. 2015, 295.) In addition, a sustainable product development system should fit into an already existing tool landscape (Hallstedt et al. 2022).

A product data management (PDM) system should be considered as a system that provides necessary information to the right stakeholder in a design process (Buchert et al. 2019, 1053, 1061). According to Cholewa and Minh (2021, 4–5, 23–24) product lifecycle management (PLM) systems, which can include not only PDM but also other functionalities, such as the order-delivery process, enable the execution and support of the circular economy in a manufacturing company. They emphasize such qualities of the PLM as product development, transparency, and value maximizing. They continue that the greatest benefit is seen when the PLM system also covers the end-of-life phase of products. Incorporating stakeholders throughout the company's supply chain into the PLM system improves access to and sharing information with the stakeholders. Such information may include, for example, the recycling or reuse rate of products and information on environmental impacts. (Saari et al. 2022, 12.)

5 METHODOLOGICAL IMPLEMENTATION OF THIS STUDY

The purpose of this thesis was to study how knowledge management of substances used in products could support sustainable product management and related informed decision-making in the case company. The aim of this thesis was to respond to the following research questions:

1) How can information related to substances and materials support sustainable product management and how important is it for the case company?

2) What are the important aspects of substance knowledge management for its successful development in the case company?

The goal was to conduct a study that supports the case company in defining the development needs of knowledge management of substances used in products.

This thesis was done as a qualitative research, and the research method was a case study. This chapter introduces the case company, the arguments for the chosen research approach and how empirical research data was collected and analyzed.

5.1 Description of the case company

The case company of this study is a large international company in the telecommunications industry. Sustainability is a strategic element of it, and it works continually to reduce negative impacts on society, people, and the planet. Material and substance information can be utilized by the various functions of the case company, such as supply chain, sourcing, product development and customer teams. The environmental team, which consists of ESG experts, is the main stakeholder that communicates the requirements for substances to the other stakeholders in the case company and drives the objectives of substance management. The substance requirements can be driven by regulations, customers and general industry guidelines and practices.

Material and substance information is collected from first-tier suppliers. Data collection can be implemented internally, or it can be outsourced. However, this study does not include the domains of data collection, or technologies used. Related tools are included due to their close connection to substance information management and informed decision-making, but they are not the focus areas of this thesis, and the aim is to get an overall understanding of the tool connection to knowledge management from the perspective of this study. Additionally, the scope of the thesis is limited to the products designed by the case company, and for example, packaging materials and manufacturing process are excluded from the scope.

5.2 Case study as research approach

The aim of a case study is to produce in-depth and detailed knowledge on a limited research object, which can be, for example, a part of a company, service, event, or process (Ojasalo, Moilanen & Ritalahti 2015, 52–53). In principle, it can be any limited case. The definition of a theoretical concept helps to form and limit a case. It is important that the researcher knows what is being studied in the selected case or cases and what the purpose of a study is. (Vilkka, Saarela & Eskola 2018, 193–194.) This study examines the phenomenon of knowledge management related to substance information and its relationship to the case company's needs to make informed decisions in the relevant processes of the case company.

Typically, the phases of a case study can be divided into:

1) Preliminary definition of a problem or development task,
2) Familiarization with the topic in practice and theory, as well as a more detailed definition of the development task based on the acquired knowledge,
3) Collection and analysis of empirical research data, and
4) Processing of results. (Ojasalo et al. 2015, 54.)

The development task often becomes more precise or even changes as the development work progresses, and after analyzing empirical research data, the theory can be re-examined if necessary (Eriksson & Koistinen 2014, 22; Ojasalo et al. 2015, 54). Also, the research question, which is the most valuable resource of the research process, can change during the research process (Eriksson & Koistinen 2014, 23).

A challenge may be to assess the coverage of collected theoretical and empirical data in relation to the research design. Defining the case and material in advance helps in assessing coverage. However, one signal for sufficient material is that it begins to repeat itself. In addition, the selection of research data must be made consciously, and the justifications must be visible in the research report in order to increase the reliability and transferability of results. (Vilkka et al. 2018, 195–196.)

This study is closely related to the principles of knowledge management of the chosen research object, which supports the choice of a case study as the research method. In addition, it was important to discover the purposes and significance of substance information for the case company. The basic principle for selecting the theoretical research material was to utilize as recent research as possible so that the results would be current and useful in defining development needs. However, when it was considered relevant to achieving the objectives of the thesis, older material was also used if no recent studies were found. When the review of the theory was done, at some point it was clear that the saturation point was reached because the sources started to repeat the findings already made.

5.3 Collection of data through semi-structured interviews and in writing

A typical feature of a case study is that it utilizes several methods in order to gain a diverse understanding of the object being studied. Methods can be, for example, various interviews, surveys, brainstorming, observing situations or even analyzing various company reports. The choice of methods depends on what kind of information is needed and what it is intended to be used for. (Ojasalo et al. 2015, 40, 55.) Typical qualitative methods are various interviews and observation (Puusa & Juuti 2020, 85).

The main data collection method for this thesis was semi-structured interviews. In addition, the interviews were expanded with an assignment in which the interviewees were asked to write a letter from the future to reflect their realistic expectations of the improvements happened in the research object at that time.

The objective of interviews is to collect research data that helps to make conclusions that can be used to answer a research problem. The aim is to get a comprehensive understanding of the research phenomenon. (Puusa 2020a, 103, 107.) In qualitative research, it is important that an interviewee is familiar with the phenomenon (Tuomi & Sarajärvi 2018, 98; Puusa & Juuti 2020, 84). In addition, the researcher's understanding of the research object and related phenomenon are prerequisites for conducting an interview (Puusa & Juuti 2020, 83).

There are many different interview methods, and they can be done face-to-face, by calls, or by using electronic communication (Puusa 2020a, 111). Vilkka (2021, 124) suggests that a semi-structured interview, also known as a thematic interview, is the most used. The thematic interview is conducted by selecting the key topics and themes of a research problem, through which the aim is to respond to the research problem (Eskola, Lätti & Vastamäki 2018, 41; Vilkka 2021, 124). The interview questions do not need to be arranged according to the theory, but the interview context can be taken into account (Puusa 2020a, 106). Additional questions may be asked during the interview if this is necessary to refine the answers (Tuomi & Sarajärvi 2018, 87–88). The emphases of the themes in the interviews may differ depending on the competence of an interviewee (Eskola et al. 2018, 30).

In this thesis, the thematic interview was applied in order to provide space for open discussion so that the phenomenon was discussed in a diverse manner. Vilkka (2021, 123) suggests that group interviews are suitable for studying community perceptions. However, for this study, individual interviews were opted to ensure the diverse views of the different experts of the case company. The aim was to bring the in-depth perspective of the subject-matter experts selected for the study.

The interview was divided into the following main themes:

1) Substance information

    a. Main benefits and challenges of restricted substance list-based and full material declarations

    b. Substance information needs

2) Uses of substance information and its availability

    a. Uses of substance information

    b. Substance information availability

3) Creation of substance information and related knowledge, and tool requirements

    a. Creation of new substance information and related knowledge and sharing it

    b. Key features of IT tools to manage substance information and related knowledge

In addition, a few sub-questions were prepared to ensure that all research perspectives are considered and the objectives of the research can be achieved. The need for sub-questions varied between the interviews. A few additional questions were also asked during the interviews to confirm the point of view of an interviewee.

The interviewees were informed about the objectives of the thesis and the main themes of the interview before the interview. This was repeated at the beginning of the interviews. The basics of knowledge management were presented before the interview and some key terms were reviewed during the discussion to ensure mutual understanding.

Eight people participated in the interviews and the sessions lasted 40–70 minutes. The interviewees represented the organizations of the case company that can be considered relevant to the case. More specifically, the participating experts were limited to those that steer the concept of sustainable product management, including sourcing, and are also familiar with the concept of substance information. This thesis does not disclose the background information of the interviewees to ensure anonymity.

The order and content of the thematic interviews were designed so that the themes were in a logical order to ensure that the interviewees understand the matter and the order would lead the interview deeper into the phenomenon. The order of the themes was the same in each interview, but the progress of the discussions varied, as did the emphasis on how much each theme was discussed. In each interview, the most attention was paid to the theme of substance information. One reason for this, however, was that during the first theme, the discussion referred to other planned themes, especially the uses of substance information. Nevertheless, all the planned themes were discussed in each interview so that the discussion was conducted thoroughly.

The interviews were conducted during the first two weeks of August 2023. After the first interview, a few themes were clarified to make them easier to understand. During the interviews, the interviewees were active and were able to explain their views without haste. The interviews were conducted using the Microsoft Teams application, which recorded audio and created a preliminary transcript that was reviewed and edited afterwards. However, the reviewed transcript did not record, for example, emphases or pauses in speech. In this phase, the interview material was numbered and anonymized. Permission for the recording was requested already in the interview invitation and confirmed at the beginning of the interview.

In addition, after the interview, the interviewees had a post-assignment to write a letter from the future, dated December 2026. A letter from future -method can be associated with a narrative research method that is used to discover what kind of aspirations people have for the future (Hänninen et al. 2021, Chapter “Kirje tulevaisuudesta -menetelmä”). However, in this study it was a continuation of the interviews in a written form. The purpose of the letter was to reflect realistic expectations regarding the evolution of substance information and knowledge management in the near future, not aspirational ones. In addition, the post-assignment gave the interviewees an opportunity to present their views even more thoughtfully. A prewarning of the assignment was given at the end of the interview, and the assignment was sent by email to the interviewee.

5.4 Content analysis of research data

The interview material and letters of this research were processed using the methods of content analysis. According to Tuomi and Sarajärvi (2018, 103, 117, 122), content analysis can be used in all qualitative research and its aim is to create a concise and general description of a research phenomenon without excluding any relevant information. The researcher should continue the content analysis until it is possible to discuss the empirical research data on a general level (Puusa 2020b, 148).

Content analysis starts with studying research data and identifying expressions corresponding to a research problem. Subsequently, the original expressions are simplified. They can be, for example, grouped into similar and different expressions. (Puusa 2020b, 151–152.) Simplification can be either condensing or splitting up relevant original expressions (Tuomi & Sarajärvi 2018, 123).

It is characteristics for content analysis that research data is classified into themes that are formed based on the research data or theory. Simplified expressions are mapped into identified themes, and these subcategories are grouped for as long as the content allows. (Puusa 2020b, 152–153.) The classification summarizes the data, and the top level is related to a research problem (Tuomi & Sarajärvi 2018, 124–125). How content analysis is formed depends on the research data (Tuomi & Sarajärvi 2018, 127), while on the other hand, two researchers would not come to exactly the same conclusion (Puusa 2020b, 155).

Based on the interview data, 165 simplified expressions were identified that could be connected to the research problem. First, they were grouped based on similarities. The next step was to identify, based on the research data, the themes to which the expressions were associated. A few expressions were mapped into more than one theme. This was followed by grouping the themes further until a generic level of the theme was reached. However, due to the broad scope of the research problem, the aim was not to create a single class combining the entire data, but to keep the grouping at a level where it is possible to answer the research questions. These generic levels are used in the headings of the subchapters of the results chapter (Chapter 6). They are also used to summarize the results in Subchapter 7.2. Appendix 1 provides an example of content analysis related to substance information formats.

This similar approach of content analysis was applied to the letters from which 25 simplified expressions were identified. However, because the scope of that data was much smaller, also the content analysis was simpler than the analysis of the interview data. Another difference was that the analysis of the letters resulted in one main grouping.

6 RESULTS

This chapter presents the research results based on the content analysis of the interviews and letters. The results of the interviews are grouped into subchapters according to the research questions, while their subchapters are named after the themes identified in the content analysis. The last subchapter of this chapter introduces the results of the content analysis of the letters. Each subchapter summarizes the results of the content analysis by theme in the form of graphs.

Some of the results of the content analysis may overlap to some extent between the research questions. This can also be seen as repetition in the results when the finding is relevant to many themes. The results contain citations from the interviewees. The citations have randomly assigned numbers (1–8), which can be used to identify how the citations are distributed among them.

6.1 Sustainable product management and substance information

This subchapter discusses how information related to substances and materials can support sustainable product management and how important it is for the case company.

6.1.1 Substances used in products as a strategic driver of sustainable change and business growth

Based on content analysis, the substances used in products are one of the strategic drivers of sustainable change and business growth. This generic level can be divided into three main subclasses, which describe the main needs why substance information is relevant (Figure 5). These are discussed in detail in this subchapter.

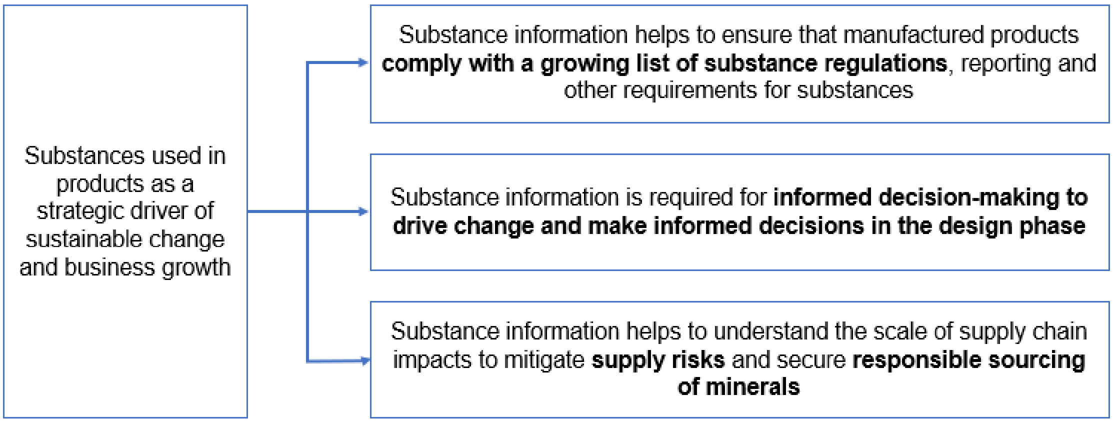

Figure 5. Uses of substance information

The interviews proved that the detailed substance information derived from full material declarations is essential for the case company due to the growing field of substance-related regulations and requirements. Ensuring compliance with regulations is mandatory, and the challenge is their increasing list. The interviews highlighted the EU's planned regulation of critical raw materials and its possible extensive reporting requirements in the form of a digital product passport. Not to mention existing regulations, such as managing the reporting of the EU REACH SVHC in the SCIP database or expiring EU RoHS exemptions, or compliance with the reporting requirements of the product environmental declaration.

It also emerged that some regions may communicate new requirements for substances at short notice, which increases the need to be prepared. These region-specific requirements can be environmental but also political or economic. Another important aspect is customer requirements that can go beyond regulations, and confirming such requirements requires detailed substance information.

It was emerged that substance information also contributes to working with internal design teams on compliance planning to ensure the continuity of product compliance, but it is also important to influence regulatory bodies together with industrial collaboration. By knowing exactly what, where, why, and how much of substances, you can influence the key materials of the case company by positively influencing the industry and ensuring business continuity in this regard.

It was emphasized in the interviews that the substances used in products are an important part of driving change and being an ESG leader. It is not enough just to comply with regulations; the proactive management of substances is the key to change. Substances and their knowledge management can be seen as a strategic element, and preparing for future needs is central. Detailed substance information provides means to analyze the sustainability potential of the case company's products. Sustainability can also be seen as a competitive advantage. Customers must be shown that the environmental impact of products decreases over time. Substance management creates sustainable business growth.

Based on the interviews, it can be concluded that substance information and knowledge enable informed decision-making and the creation and implementation of a substance strategy. Substances can be, for example, ranked according to an ESG risk and the use of substances with the most negative impact should be reduced or even phased out. The interview material also revealed that impacting suppliers to change materials is one way of influencing, and such work cannot be done efficiently without knowing which supplier provides exactly which material.

The interviewees highlighted that the choices made during the product development phase play an important role in the implementation of the substance strategy. An informed choice of materials, together with an understanding of the amount of material, is one of the elements that makes it possible to design sustainable products. Substance information enables more effective promotion of environmentally friendly design, especially when the information is integrated into design tools. In addition, substance information can be used to calculate more accurate environmental impact of products instead of theoretical calculations.

> "In really taking a lead in sustainability, you kind of have to rank all these substances into from worst to best, and then start coming up with a mechanism to rate substances so that ultimately you can rate the design." (5)

The aspect of promoting the circular economy was separately raised in the interviews. Informed material choices increase the circularity of products. Knowing the materials in the products also helps move forward to get higher levels of recyclates into them.

Based on the interviews, aspects related to supply risk and responsible sourcing of minerals also emerged. Substance information helps understand the extent of supply chain impacts to mitigate supply risks and secure a responsible supply chain for minerals. The scope of responsible minerals is expanding and understanding which minerals are associated with which supplier helps the case company assess the impact of the supply chain and target supply chain inquiries with the right suppliers. Similarly, the supply chain can be assessed to mitigate supply risks. For example, geopolitical issues are driving the case company to increasingly understand what materials are used and where they come from.

> “It's becoming like a risk management issue, not only sustainability.” (1)

6.1.2 Lack of substance information as a barrier to achieving ESG goals

To determine the importance of substance information for the case company, content analysis revealed that a lack of substance information can be a barrier to achieving ESG goals. This generic level has two subclasses based on the analysis: incomplete information causes uncertainty and growing needs for substances related information (Figure 6).

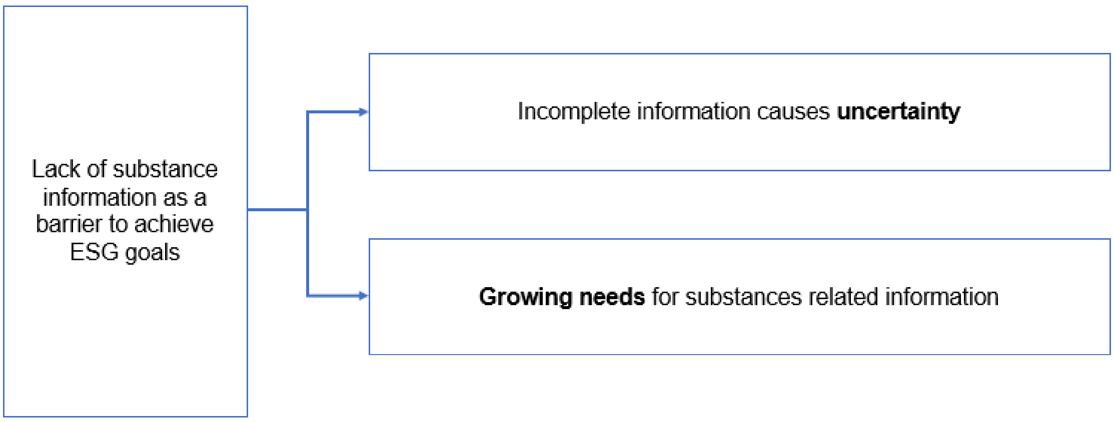

Figure 6. Importance of substance information

The interviews concluded that rapidly evolving requirements require much attention in managing substance information. The lack of accurate information on substances can be a barrier to effectively pursuing ESG objectives related to substances, both internally and externally, for example with suppliers. A strong mechanism for implementing a substance strategy cannot be created without proper information.

Incomplete information requires a lot of expert knowledge to manage substance requirements, and then decisions are based on assumptions, not information. The information gap can create uncertainty, and comprehensive substance information is needed to prepare for the future.

Additionally, the needs for substance related information exceed the full material declaration. The interviewees mentioned the need to know the amount of recyclates used in products to drive the circularity of products. Even transparency throughout the product value chain to calculate the actual environmental impact may be necessary. Mitigating supply risks also requires visibility throughout the supply chain, which means, for example, identifying the production sites of each material included in the components.

> “It will start hitting us from all sides. So, if you think strategically, you start now. If we don't, then I think it will push us into a reactive mode sometime in the next 10 years where solving the issue at the end is always more expensive than starting maybe a little bit low key.” (5)

6.2 Important aspects of substance knowledge management for its successful development

The second research question was to find the important aspects of substance knowledge management for its successful development in the case company. The first subchapter discusses the results of the substance information reporting formats. The selection of a substance information declaration format is essential as it defines other information management needs, such as tools, and opportunities for substance knowledge management. The second subchapter presents the results on how the challenges of substance information management can be addressed. The remaining subchapters focus on the tool-related results and knowledge creation through substance information, as well as the importance of expert knowledge. They were found to support informed decision-making.

6.2.1 Full transparency of substances for preparing requirements for substances

As discussed in the previous subchapters, substance information provides tools to prepare for increased requirements for substances. Companies can collect information using a restricted substances list (RSL) –based declaration (“Yes” or “No” answers) or a full material declaration (FMD). According to content analysis, full transparency of substances is required for preparing requirements for substances. The subclasses of this generic level are in Figure 7. They highlight the information gap of RSL-declaration, the importance of FMD and its challenges, and the increasing information needs related to substances.

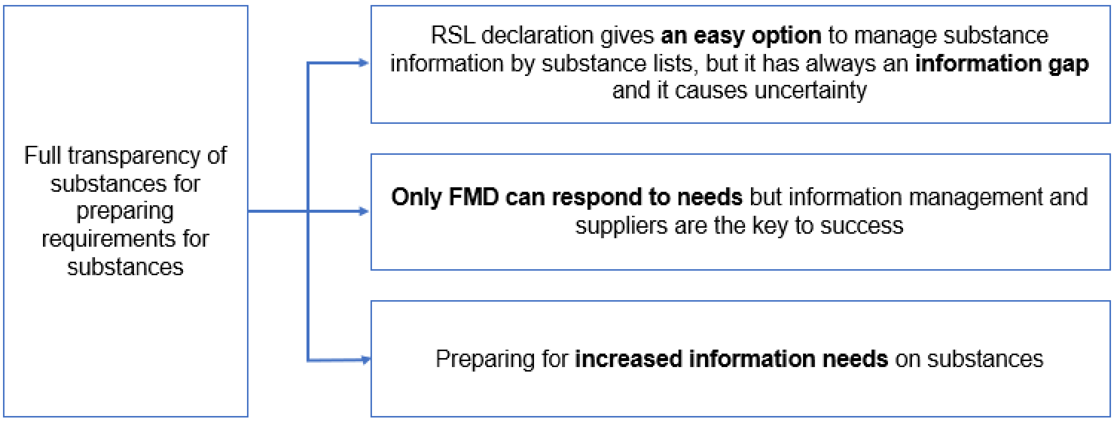

Figure 7. Substance information

The RSL declaration can be modified to meet some company needs, but only FMD can provide full transparency about substances in products and create real value. While one interviewee suggested that the RSL declaration can handle various substance requirements, others strongly believed that only FMD has the required transparency to meet the requirements. The FMD provides a way to manage different requirements proactively and it can produce real substance information and knowledge.

> “So, if we give them distinct, then the benefits are just the amount of data that we can turn into real information and knowledge, and not just about a bit of compliance.” (5)

The RSL declaration provides an easy opportunity to manage substance information by substance lists. The interviewees commented that the RSL declaration facilitates the management and use of substance information due to the groups of substances, which often form the basis for such declaration. They described that the RSL declaration provides pre-analyzed information.

However, the challenge is that the RSL declaration has always an information gap and it creates uncertainty. It is always a snapshot and gives only limited visibility to the substances used in products. The RSL declaration can only contain the company's most strategic substances, which often means regulated substances because suppliers can be reluctant to disclose anything other than regulatory lists in the list format. This limited view can therefore only provide a limited amount of information, and a limited amount of knowledge can be derived from it.

In addition to the information gap, it was expressed that the collection of the RSL declarations must be repeated regularly in order to keep pace with regulatory changes. However, there may be a delay between the entry into force of a regulation and the receipt of an up-to-date declaration. This is the opposite of the FMD approach. The FMD approach requires only the change management after initial FMD collection, and the information can be considered valid until the item supplier makes any changes to materials and informs about them through the change process. One interviewee claimed that the RSL declaration could be proactively updated to cover emerging regulations and the case company's strategic substances, while another described adding too many questions to the RSL declaration makes it an almost FMD. Additionally, the traditional RSL declaration does not include the weight of substances in a product, which is valuable information to promote sustainability.

However, all interviewees admitted the difficulty of FMD management. That is a huge amount of information that needs to be collected and maintained. This emphasizes the importance of information management and tool capabilities. The FMD is only useful when information management is done properly. The additional information needs regarding substances discussed in Subchapter 6.1.2 cause even more complexity.

One point for the success of FMD management, which appeared in the interviews, was that the FMD is dependent on information received from suppliers.

The FMD only works if it is complete, and the quality of its information is good. Differences in the reporting formats used by companies can pose an extra challenge. In addition, managing proprietary substances that are not disclosed by suppliers needs to be solved in such a way that the case company can rely on the information. To ensure the information quality of the FMDs, suppliers shall be properly trained on the reporting requirements. It was also acknowledged that sometimes any information is better than no information.

6.2.2 Organizational commitment and solid plan for successful development of substance knowledge management

Based on content analysis, organizational commitment and a solid plan for developing knowledge management are essential. The main findings are shown in Figure 8.

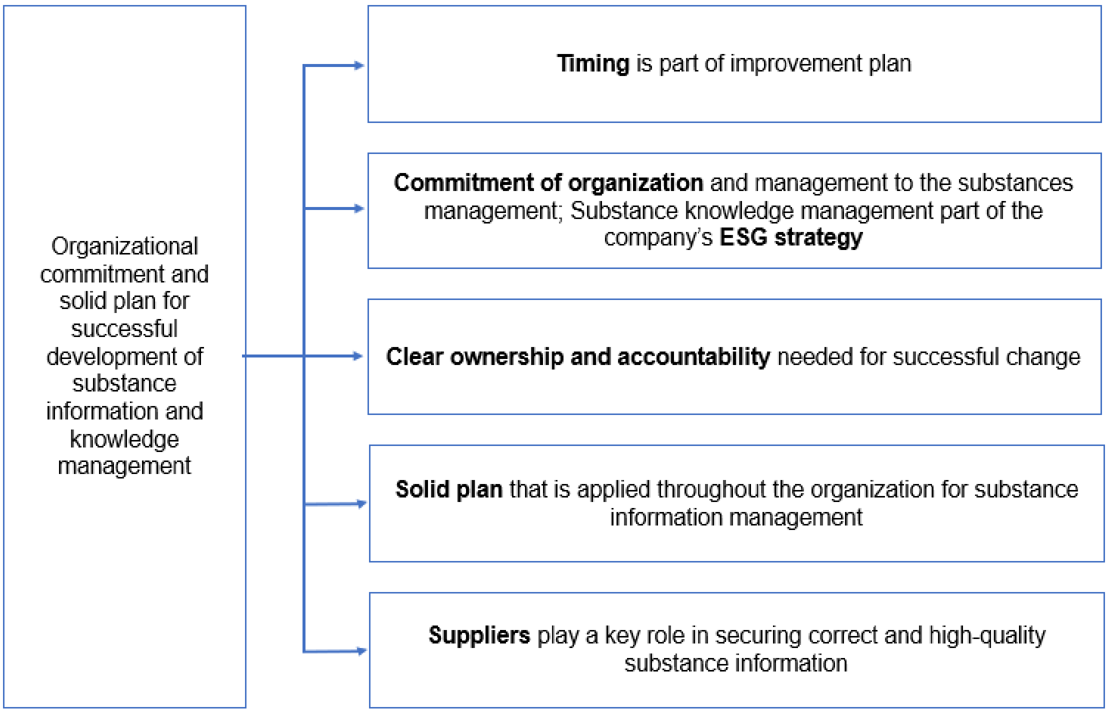

Figure 8. Development of substance information and knowledge management

While most of the interviewees saw an urgent need for improvement of substance information and knowledge management, one challenged this by stating that the case company needs a long-term strategic plan that is ambitious, rather than immediate actions. This was justified so that the case company can manage the substance requirements with the existing process, and it is more important to look for long-term strategic objectives for substance management. Those objectives include also applying advanced technologies to collect information, such as blockchain, and analyzing information using artificial intelligence. In addition, the interviewee had a vision of a business consortium that would manage full transparency of substances and help the entire industry. It was emphasized also in the other interviews that the case company must keep up with digital development.

> "We're in a digital world, and because of that, all processes all the way through to the earliest stages of material extraction and processing will then have to be a digitized, and a lot of this is being built around what they call a mirror world or a digital twin." (7)

The interviewees agreed that managing FMDs is challenging due to the large amount of information. However, they emphasized that the challenges of the FMDs must be addressed and can be overcome with a solid plan for substance information and knowledge management and organizational commitment.

To ensure the success of substance information management, the following points were identified based on content analysis of the interviews:

1) Organizational commitment, as well as the commitment of the management concerned,

2) Clear ownership and accountability in substance information management,

3) A solid plan for substance information and knowledge management and,

4) Suppliers play a key role in securing correct and high-quality substance information.

Management support is needed, and substance knowledge management should be part of the company's ESG strategy. There must be also an organization-wide commitment to substance management and the achievement of its objectives. Secondly, there is a need to re-evaluate the right organization in the case company that owns and controls substance information. Information management requires a lot of resources and funding, which is why clear ownership is needed.

A solid plan ensures that the implementation is successful. It saves money and resources. The plan is needed, for example, for information needs, information collection and tools, as well as a schedule for meeting the requirements. Another aspect is to ensure that substance information is available and used, and that experts analyze the information and use it to guide the substance strategy of the case company.

Relevant organizations in the case company should apply the same processes and the same way of working. The information availability ensures its effective use. Information that is used regularly should be easily available. The stakeholders of the substance information should be made aware of the available information in order to ensure that it is used. In addition, they should also know who to contact with substance information needs or questions.

> “If there are problems, it can be a bit challenging to try to dig up the information for your own purposes that there may be room for improvement.” (3)

Lastly, supplier onboarding is key. Suppliers provide information on substances, and this information must be reliable. They are therefore at the heart of the process. Onboarding suppliers already in the planning phase of the substance information collection and ensuring that they have a capacity to perform the required reporting is the foundation. In addition, continuous supplier training is needed to secure the continuity of high-quality substance information collection. Moreover, it was emphasized that a company-wide process not only optimizes the case company’s efforts with suppliers, but also helps suppliers manage requirements for substances.

> “I think when it comes to the work with suppliers, it needs to be very much aligned and consistent. So, we need to have some consistency in the approach, and everybody can only win from this.” (1)

6.2.3 Effective use of substance information and knowledge creation through tools for informed decision-making

The third aspect identified through content analysis was that relevant tools are enablers for the effective use of substance information and knowledge creation. Figure 9 lists the main characteristics of this finding.

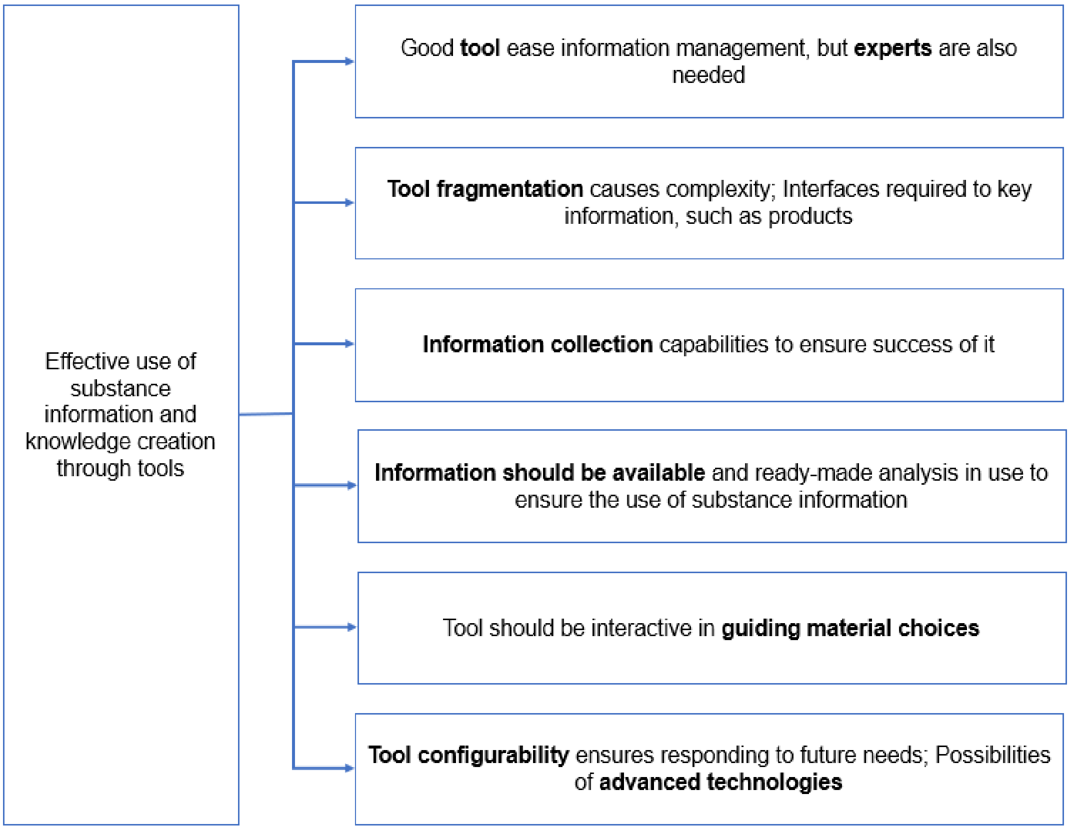

Figure 9. Informed decision-making and tools

As discussed in the next subchapter, ESG experts are needed to promote the use of substance information and a tool alone is not enough. However, the interviewees also considered the features of tools important. The tool allows access to substance information. Adequate features will facilitate information management, which is highly relevant for substance information, given the scale and complexity of it.

> "I think that if we don't have a capable tool to extract the information that we need and when we need it, it's more or less useless. And I think that a good system is as important as the data itself." (2)

The interviews revealed that the fragmentation of the tool landscape can cause complexity in the management of information and knowledge, and interfaces with key information are needed. The complex environment associated with the end-to-end product management adds an additional challenge to the concept. A centralized tool that is either embedded in the company's product data management system or has an interface to is essential. It is important that information on substances is linked to suppliers, components, and products. The need to combine sales and delivery information also emerged. Optimally, the interfaces cover the comprehensive management of the entire value chain of substances in the case company.

Substance information management begins with information collection, which is thus an important starting point for the process. Companies in the electronics industry can transfer FMDs using various forms, and the interviewees had different opinions about the reporting format. One interviewee advocated that various forms from suppliers should be accepted to prevent problems in collecting information from them. The other was in favor of a standardized information exchange form. The third could not give any straightforward answer. In addition, it was raised that ideal would be if suppliers can enter substance information into the company tool through the interface. The interface could dynamically give feedback to the supplier on possible shortcomings in the information provided.

> "If we would only accept one standard of reporting, would that create a problem with those suppliers?" (5)

There was also discussion about the importance of reporting and analytical capacity to ensure the use of information on substances. Access to information must be ensured, and reporting and analysis must be easy. The basic needs of information analysis must be translated into the tool in the form of ready-made reporting. However, the tool should also have advanced analytics capabilities that meet all reporting needs. Visualization of information also came to the fore.

> "I would make them [to stakeholders] the data available so that everybody can follow a kind of pull approach and pull exactly the data that is most suitable for their part of the business." (4)

Material choices and understanding the impact of each material are important in promoting sustainability and this next level of information should be available in the tool. It was emphasized that the tool should guide material selections at an early design phase. It should flag bad selections, give environmental scores at the material level but also at the component and product level, and it should even guide designers to make better choices. An environmental score is needed for carbon footprint, but a general sustainability score was also emerged in the discussions. The sustainability score would evaluate materials across different dimensions of ESG, such as child labor or hazardous substances, and give even more accurate understanding of why a material has a certain score.

Substance requirements can change and not everything can be implemented immediately, so the configurability of the tool ensures that future needs are met. An open IT application allows customization of functionalities, such as reports and analytics.

In addition, the potential of advanced technology was pointed out. Automation and artificial intelligence can help improve and manage information better. While another noted that such features do not need to be prioritized in the case company's substance information improvement project but can be considered over time when the basics are in place; another said that the change plan should be based on the advanced technology and the change should be made when such capabilities are ready. The interviewee had a long-term vision that the advanced technology would make the whole concept more self-governed and eliminate the human element when possible.

> "We can focus more on how do we apply the AI and the techniques so that we can push a button and these things are automatically created in the context of whatever government or whatever customer or whatever country is asking for and we can give them a customized report based on the whole AI methodologies that we have implemented automatically" (8)

6.2.4 Expert knowledge in promoting change through substance information

The last element identified as an aspect of substance knowledge management is expert knowledge. ESG experts are needed to identify the uses of substance information, create relevant knowledge, and promote and share it (Figure 10).

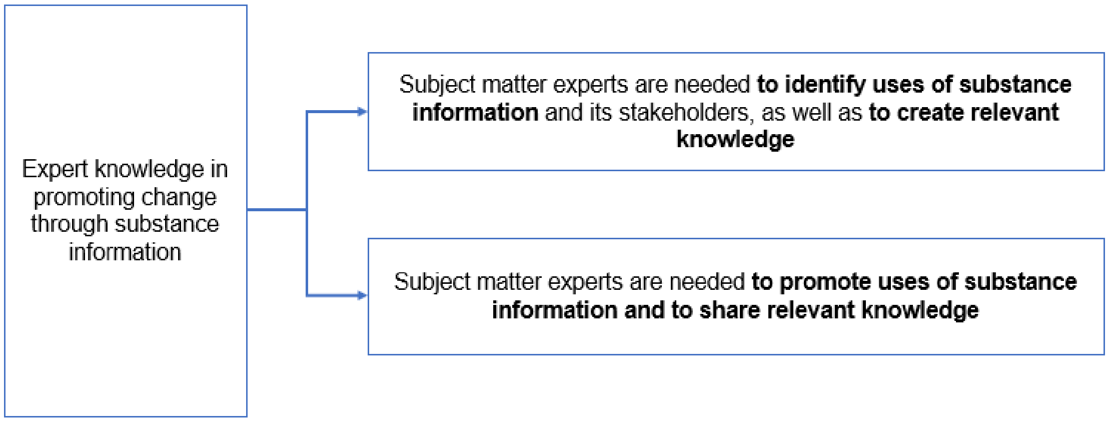

Figure 10. Informed decision-making and expert knowledge

It became clear from the interviews that substance information and advanced tools are useless if the information is not used. Knowledge of ESG experts is the key to driving sustainability. Knowledge created from substance information can be utilized in creating the case company's strategy and sharing knowledge in relevant functions and at a higher organizational level.

These experts are needed to identify how substance information can be utilized and who its stakeholders are. They are needed to interpret and analyze substance information and create relevant knowledge. All this needs to be brought to identified stakeholders and steer the implementation of requirements and make sure that information is used in relevant decision-making. Change will not happen if no one drives it. The importance of expert knowledge is emphasized in the product development phase because material selections play a key role in promoting sustainable development.

> "The expert knowledge has to be really aimed for the design phase, not the production phase." (6)

> "So that [creation knowledge] for me is like further analysis and then presentation of this to the stakeholders be that the risk management or environmental strategy." (1)

6.3 Importance of continuous development of substance knowledge management

Based on content analysis of the letters, the continuous development of substance knowledge management is important. Information accuracy and growing requirements are ongoing challenges. However, informed decision-making is expected to improve in the short term. This is shown in Figure 11.

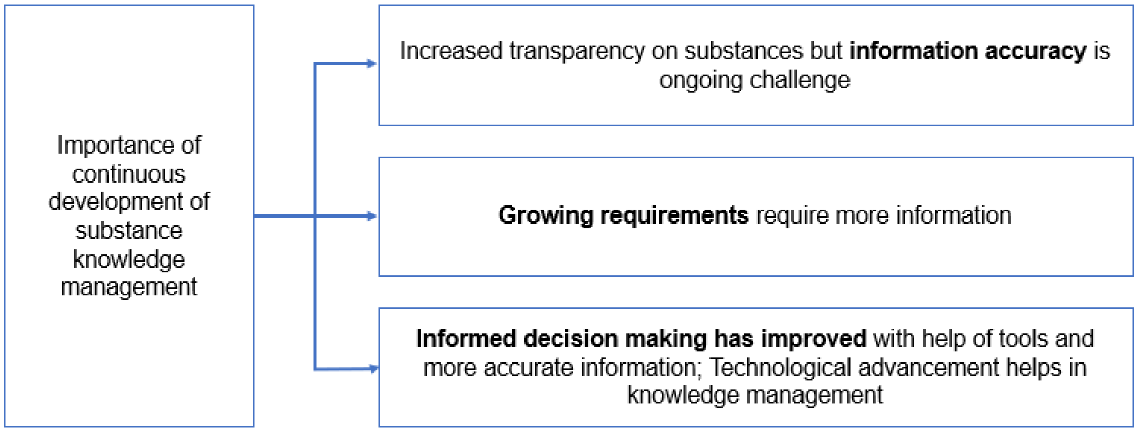

Figure 11. Expectations for the development of substance information by the end of 2026

The letters showed that most interviewees expect increased transparency of the substances in products by the end of 2026, but information completeness and accuracy could be still a challenge. Technological advancement and global initiatives have improved the management and transparency of substance information.

The interviewees who were more conservative regarding the pace of change in substance knowledge management expressed that in 2026 it is time to start developing substance knowledge management because of its rising importance. The other interviewee further stressed the need for urgent development to keep pace with the requirements for substances. The ongoing challenges of substance information availability and optimization of information management resources need to be addressed.

The interviewees highlighted again the growing requirements for substances. Even more information has been collected than FMDs, such as recyclates used in mechanics, and new requirements are emerging, for example, related to the production sites of components. It was stressed that proper knowledge management is still crucial for managing a complex field of requirements.

According to the letters, the increased accuracy of substance information has improved making informed decisions. For example, design tools guide component selection and integrate the ESG risk analysis. ESG experts can use efficiently substance information in innovating, however, innovation with substance information could be even more effective. Also, technology, such as artificial intelligence, helps in substance knowledge management, but knowledge sharing needs to be improved.

7 DISCUSSION

This chapter summarizes the study, the main results and conclusions drawn. In addition, the reliability and ethics of research are assessed and new topics for further research are discussed.

7.1 Summary of the research

As already stated in the introduction, sustainable product management and related substance information management are not novel concepts. However, due to growing requirements of sustainability and supply risk mitigation, it was highly relevant to look at substance information management. In addition, added value to the research problem has been obtained because it has been examined from the perspective of knowledge management.

The purpose of this thesis was to study how knowledge management of substances used in products could support sustainable product management and related informed decision-making in the case company. The aim of this thesis was to find out how information related to substances and materials can support sustainable product management and how important it is for the case company. In addition, it was studied what the important aspects of substance knowledge management are for its successful development in the case company.

This thesis was done as a qualitative research, and the research method was a case study. The compilation of the theory started at the end of 2022 and continued until June 2023. After this, the interviews were planned and conducted during August 2023. Content analysis of the interviews, as well as writing the results and discussion, were done immediately after the interviews and the project ended in November when the thesis was finalized.

The theory of knowledge management played an important role, especially in the planning of the interviews. Content analysis of the research data helped answer the research questions. The research results and theory together created a baseline that the case company can use in developing its substance knowledge management process.

It can be concluded that the purpose of this thesis was achieved by identifying how knowledge management of substances used in products can support sustainable product management and related informed decision-making in the case company. More specifically, the results can support the case company in defining the development needs of substance information and in knowledge management of substances. The goal was not to define detailed requirements but to define a baseline for the project to improve substance knowledge management so that the case company can get an understanding of the basic elements of knowledge management concept to be considered in developing it. Although the research was a case study for a case company, the commonalities between the research and the theory support that the similar framework, which is a conclusion of this study, can also be used by other companies seeking sustainable product management with substance information.

7.2 Main results and conclusions

Based on the generic levels of the interview content analysis, the results can be summarized as follows:

The substances used in products are one of the strategic drivers of sustainable change and business growth. Full transparency of substances provides tools to prepare for substance requirements, and a lack of substance information can be a barrier to achieving ESG goals. Organizational commitment and a solid plan are prerequisites for the successful implementation of substance information and knowledge management. The substance information tool connected to the product data management system ensures the availability of substance information and enables the efficient use of it in decision-making and knowledge creation. However, a tool alone cannot make a change, and the knowledge of ESG experts is the key to driving change through substance information. The continuous development of substance knowledge management to meet growing requirements is crucial.

As a result, a framework for substance knowledge management was formed based on the theory and results of this study. The framework presents the main building blocks that the case company can use in developing an optimal knowledge management concept for substances used in products.

The key building blocks in the framework are substance information management, knowledge-based management, and the roles driving its different elements. The elements in the building blocks enable substance knowledge management, which aims to drive sustainable change and business growth with informed decision-making. The framework is presented in Figure 12 and its connection to knowledge management, as well as its different blocks are discussed in the following subchapters.

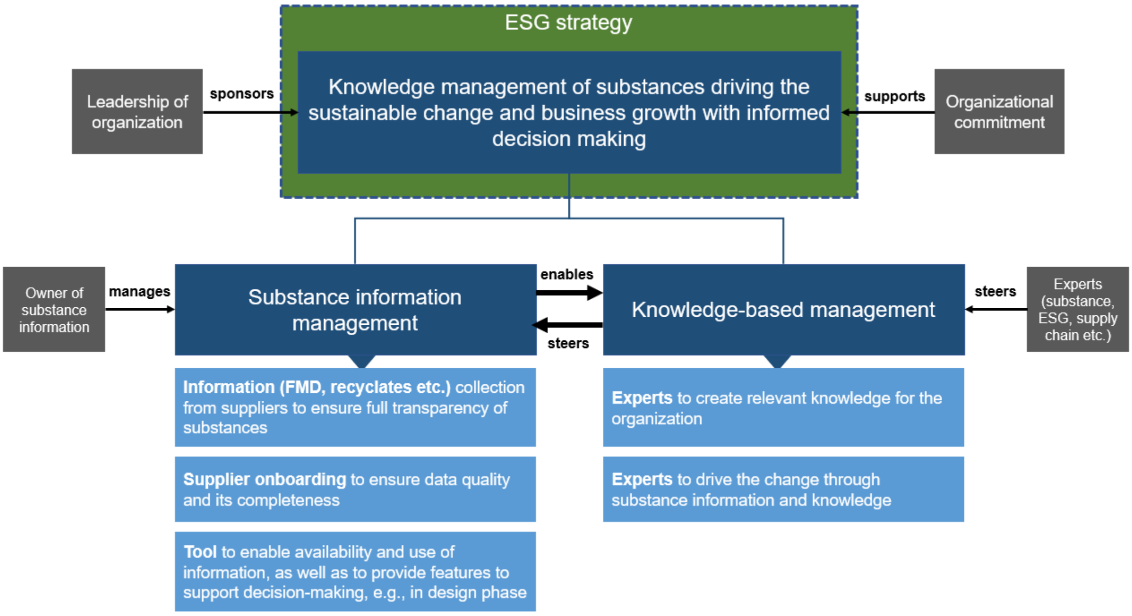

Figure 12. Substance knowledge management, its key concepts and responsibilities based on the research results (adapted from Finto 2018b and the research results of this thesis)

7.2.1 Developing substance knowledge management in the case company

The results of this study showed that the substances used in products are a strategic element for the case company to drive sustainable change and business growth in a transparent manner. The interviews emphasized the need to drive change, not just keep pace with growing requirements. The approach to substance management should be proactive rather than reactive. A proactive approach cannot be achieved without full transparency of the substances in products, which is in line with the theory presented in Subchapter 4.1. The active strategy integrates knowledge of substances into a company's management systems and creates value for the company (Rossi 2014, 3–4).

The concept of material and substance compliance has traditionally guided the need to know the substances in products. However, based on the literature presented in Chapter 2 and the interviews, complying with regulations is no longer the only reason. To reduce the environmental and social footprint of products and supply risks, it is essential that the case company has **a strong mechanism to address these challenges through substance information**.

The management of substance information and related requirements requires a systematic approach to control this complex matter. Connecting knowledge management principles can help reduce complexity. Knowledge management offers models and tools for adopting knowledge in the daily operations of organizations and knowledge is an asset that creates value (Laihonen et al. 2013, 8, 24). This value is needed to address the challenges of substances. Additionally, information creates opportunities for innovation (Käpylä & Salonius 2013, 56), which is relevant to promoting sustainable development. In summary, knowledge management strives to create value with information, knowledge, and expertise (Finto 2018b), which is also the purpose of substance knowledge management.

Optimally, substance **knowledge management is part of the company's ESG strategy**. Improved and comprehensive knowledge management of substances would increase confidence and opportunities. To develop the knowledge management concept of substances successfully, there must be **a solid plan for substance information management and further to knowledge management**. The presented framework can be applied to the creation of an improvement plan for substance knowledge management and for its continuous development. Appendix 2 summarizes the uses of substance information and their main aspects based on the theory and interviews to be considered when developing the knowledge management concept of substances. The information in Appendix 2 helps understand information needs and, through the purposes of substance information, gives an idea of how the information should be available for efficient decision-making.

Even though the common view by the interviewees was that substances are a strategic element to the case company, there were some differences between the interviewees on timing when an improvement of substance knowledge management concept should begin. Most of the interviewees saw an urgent need for a change, but a few were more conservative and saw this as a longer-term strategic improvement plan together with technological advancement. Timing is part of the development plan to be created, however, the planning of substance knowledge management, whether it is a short-term or long-term plan, must be started without delay.

As the research data collected using the letters indicated, the completeness and accuracy of information can be an ongoing challenge. The complexity of requirements requires constant attention to knowledge management. The iterative process of knowledge management presented in Subchapter 3.2 can be applied to develop the process ensuring that the case company's knowledge management concept is ready to reply to requirements and challenges proactively.

7.2.2 Substance information management

Substance information management is a prerequisite for knowledge-based management. Information management includes tools (Leskelä et al. 2019, 15), as well as the creation and management of information (Käpylä & Salonius 2013, 7).

The results of this study emphasize the need for **full transparency of substances** in order to prepare for substance requirements and enable informed decision-making. The literature supports this and, for example, Schenten et al. (2019, 36) emphasize that the FMD is a prerequisite for achieving the control of substances in products. In addition, the interviews highlighted that new information needs are emerging, such as the amount of recyclates in products. The interviews highlighted that **supplier onboarding** is important for the substance information process to ensure successful information collection and to improve information quality.

The interviews showed that the features of **the substance information tool** play an important role to support informed decision-making in the case company. The features of the tool enable the efficient use of substance information and the creation of knowledge. The features should support decision-making, for example, by guiding the choices of materials and components already in the design phase. This is in line with the literature. For example, Hallstedt et al. (2022) state that the early integration of sustainability aspects to guide decision-making is essential. In addition to indicating material compliance, the tool should calculate the overall ESG risk.

Technological advancement will affect the management of substances. It affects the requirements for substances, but also helps to meet the requirements. This emerging field of technology seems to be relatively new in the context of substance management, and in this regard, research is lacking.

7.2.3 Knowledge-based management

Knowledge-based management uses information (Kosonen 2019) and thus supports informed decision-making (Käpylä & Salonius 2013, 7). According to the results of this thesis, ESG experts are needed **to steer the use of information, create knowledge, and promote change** through substance knowledge. Laihonen et al. (2013, 44) also underline that benefits can only be obtained when knowledge is interpreted correctly, it is relevant, and it is in the right person at the right time and in a usable form and is used.

Based on content analysis, this is an important element in the framework, because information or tools alone do not solve issues, but ESG experts are needed to steer the use of information. The theory also revealed that effective substance management must be integrated with tools, but substance experts are needed to interpret information (see Subchapter 4.2) and knowledge of materials often requires the support of a materials expert (Brambila-Macias & Sakao 2021, 6).

7.2.4 Key roles of substance knowledge management

According to the results of content analysis, the roles identified in the framework are important for the successful implementation of substance knowledge management. **Sponsorship of management** is required to drive knowledge management efficiently. It supports the acquisition of the needed resources, such as tools, but also gives a signal to the case-company about the importance of substance management objectives. In general, **the case-company must commit** to the topic. Moreover, the **ownership of substance information** must be clear, and the owner is accountable for implementing the building block of substance information management.

As discussed in the previous subchapter, **ESG experts** drive the use of information and knowledge creation. They communicate substance information requirements to the owner of substance information to ensure that the case company can respond to the requirements in a timely manner. Regular monitoring of knowledge-based management needs is necessary to ensure that the case company can react to the requirements. In conclusion, the experts play a key role in the case company's substance knowledge management process.

7.3 Examination of reliability and ethical considerations

The reliability and ethics of research are supported by transparent reporting on what has been done and how, and what things have been discovered (Eriksson & Koistinen 2014, 31; Ojasalo et al. 2015, 105; Aaltio & Puusa 2020, 181; Vilkka 2021, 198). In addition, the application of several different methods increase reliability (Ojasalo et al. 2015, 105).

Research ethics is valid throughout the research process, and research and presenting results are done honestly, carefully, and accurately. Assessing reliability is relevant through the research project and the research must be able to demonstrate the choices made for the research (Vilkka 2021, 41–42, 197).

Systematic documentation was started from the very beginning of this thesis project. It helped go back when it was necessary. The thesis focused where possible on the most recent research, specifically in compiling the theory of substance information and sustainable product management. This supported one of the justifications for this research that was to increase understanding of topical aspects of sustainable product management. When older material was used, it was a conscious choice to achieve the objectives of this thesis. When the review of the theory was done, at some point it was clear that the saturation point was reached because the sources started to repeat the findings already made.

The choices for the methodological implementation of this research have been presented and justified in this report. The data collection methods selected for the thesis are expert-oriented, and the results are based on the interviews with the experts of the case company. It is important for the reliability of research that different parties understand the research framework in the same way and are open-mindedly involved. All the interviewees for the thesis were familiar with the concepts of substance information and sustainability, having possibly their own area of expertise. In each interview, the basics of knowledge management was introduced, and some terminology was clarified during the interview to ensure that there is mutual understanding.

The researcher's competence also has an impact. In this research, the researcher knew the subject and the interviewees well, and it increased understanding and reliability since misunderstanding could be avoided. However, it was important to understand that the researcher's knowledge should not affect conducting the research or the research results, but neutrality was kept during the research project.

One part of research ethics is how research data is stored and anonymity ensured (Vilkka 2021, 47). The interview data was anonymized and managed by following the information security instructions of the case company. The material was stored in the case company's IT system in the cloud and protected with a password. The interview material was deleted after the project. Everyone participating in the study was told how the interview content is used and that the thesis does not reveal anyone's identity.

Although two methods were applied, it can be stated that this study did not fully follow the typical feature of case studies to apply multiple methods, since both methods applied the personal vision of the expert. This can challenge reliability. However, different expertise of sustainable product management and supply chain was well presented in the interviews and the choice of these interviewees supported researching the defined case. In addition, the content of the interviews started to repeat, which indicated that in this case saturation was reached. The interviewees were provided with a chance to give their view even more thoughtfully and they were asked to write a letter from the future, and it can be considered that it increased reliability.

7.4 Topics for future research

There are many future research possibilities due to increasing requirements related to sustainability. It can be said that the scope of this research was quite broad, and the different aspects of substance knowledge management deserve dedicated attention.

Additionally, this research ruled out, for example, information collection methods and related technologies. Information collection can be arranged internally, but there are also third-party service providers and centralized substance compliance platforms providing means for substance information management. Moreover, as it emerged in the research results, advanced technologies, such as blockchain, artificial intelligence and the Internet of Things, need more attention. These technologies can have a significant role in enhancing information exchange and information analytics in complex supply chains.

It is certain that the development of policies in the different regions, for example the EU Green Deal, together with technical advancement, will change substance information exchange and reporting requirements. Companies need to monitor this change closely and this area needs to be further researched to increase understanding.

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APPENDICES

Appendix 1. Example of content analysis related to substance information formats

SIMPLIFIED EXPRESSION	GROUPING1	GROUPING2	THEME1	THEME2	GENERIC LEVEL
Knowing level of recyclates	Generic	Information requirements	Increased needs of substance details; even traditional FMD is not enough	To be prepared for increased needs of substance information	Full transparency of substances for preparing requirements for substances
To be ready for changes in future	Generic	Information requirements			
Transparency to the whole value chain to calculate environmental impact	Generic	Information requirements	Increased transparency to the whole supply chain		
Transparency to the whole supply chain and materials sources to mitigate supply risks	Generic	Information requirements			
Knowing substance amount (not only presence)	RSL	Content	Challenge: Limited visibility to substances	RSL-based declaration gives an easy option to manage substance information by substance lists, but RSL-based declaration has always an information gap and causes incertainty	
RSL is a reactive way to manage substances due to limited amount of information	RSL	Content			
RSL can include only strategic substances (restricted/monitored)	RSL	Content			
RSL to be updated proactively to cover new regulations	RSL	Content			
Delay between legislation change and getting an up-to-date RSL	RSL	Content			
RSL can only manage substance compliance	RSL	Content			
Adding too many questions to RSL template makes it almost FMD	RSL	Content			
Challenge to collect RSLs regularly for all items	RSL	Data collection	Challenge: Repeated inquiries		
Managing repeated inquiries	RSL	Data collection			
Ease of RSL management; to add new substances / substance groups when needed	RSL	Management of RSL	Benefit: Ease of management due to substance groupings; readily analyzed information		
Ease of using RSL; readily analyzed information due to substance groupings	RSL	Management of RSL			
Ease of management RSL due to limited information asked in the template	RSL	Management of RSL			
FMD is a proactive way to manage substance requirements	FMD	Knowledge	Only FMD can create knowledge that responds to company needs	Only FMD can respond to company needs, but information management and suppliers are key to success	
Only FMD can create real substance information or knowledge	FMD	Knowledge			
FMD is preferred format	FMD	Knowledge			
To be ready for sudden inquiries	FMD	Knowledge			
Huge effort of FMD management	FMD	SI management	FMD is only useful when information management is done properly		
Difficulty of using and analyzing information of FMDs	FMD	SI management			
Importance of SI management due to huge amount of information	FMD	SI management			
No standardized way to collect information; differences on reporting	FMD	Data collection; suppliers	Successful FMD management is dependent on information received from suppliers		
Difficulty of collecting information due to supply chain pushback	FMD	Data collection; suppliers			
Managing proprietary substances can cause additional inquiries	FMD	Data collection; suppliers			
Supplier training to ensure data quality	FMD	Data collection; suppliers			
FMD works only if it is complete	FMD	Data collection; suppliers			
Sometimes any information is better than no information	FMD	Data collection; suppliers			

Figure 1. Content analysis related to substance information formats

Appendix 2. Uses of substance information and their main aspects in developing substance knowledge management

Table 1. Summary for the uses of substance information and their main aspects in developing substance knowledge management

Uses of substance information derived from FMDs	Important aspects to support in developing substance knowledge management
Compliance with regulations and requirements of other stakeholders, such as customers	Regulations can restrict the use of substance or require reporting of them (Miehe et al. 2015, 289–290; Interviews) Growing list of regulations (Interviews; Rolke et al. 2019, 172), for example the proposed EU Critical Raw Materials Act (European Parliament 2023; Interviews) or other policies for the circular economy, such as a digital product passport (European Commission 2023a; Interviews) Some requirements may come at short notice (Interviews) Requirements of stakeholders, such as customers, can go beyond regulation (Interviews) Proactive management of requirements (Schenten et al. 2019, 38; Interviews) Industrial collaboration on managing substance compliance (KEMI 2016, 17; Interviews and internal compliance planning to ensure continuity of product compliance (Interviews)
Driving change	Proactive management of ESG matters (Interviews) and strategic management of substances (Gaustad et el. 2018, 27–28, 31; Interviews) Innovation and finding the potential of sustainable development (Interviews) Integration to decision-making and design tools enables informed decision-making (Buchert et al. 2019, 1061; Hallstedt et al. 2022; Interviews) Influencing on material choices in the supply chain (Interviews)
Responsible sourcing of minerals	Securing a responsible supply chain of minerals (Young et al. 2019, 18; Interviews) Voluntary expansion of minerals for company's due diligence process (Franken & Schütte 2022, 654; Interviews)
Mitigating supply risks	The availability of materials can be related to geological resource scarcity or access to supply (Kalaitzi et al. 2018; Charles et al. 2020, 2; Interviews), for example due to geopolitical tensions (European Commission 2023c; Interviews) Successful supply chain strategy requires detailed substance information (Kalaitzi et al. 2018, 800; Interviews) Supply issues can require immediate attention and information about their impact on the supply chain (Interviews)
From FMDs to more detailed information	FMDs are not enough in the future, but the requirements are growing, for example: 1) amount of recyclates used in products, and 2) visibility throughout the supply chain, for example, to identify the production sites of each material included in the components (Interviews)