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The impact of the wet dyeing process on the environmental sustainability

A case study of IKEA and their usage of water, energy and chemicals

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Thank you

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Abstract

Background: As a company it is more important than ever to consider the environmental sustainability aspect within the whole supply chain and all the stakeholders. Studies show that people's concerns about environmental sustainability increases and will continue to grow in the future. The wet dyeing process is the part of the textile production that consists of liquor and contains three main steps which are pretreatment, coloration and finishing. This process is presented as the most water, energy and chemicals consuming process within the textile industry and because of that, it is important to investigate it to be able to improve the environmental sustainability.

Purpose: The purpose of the thesis is to increase the understanding of IKEA's suppliers' current usage of water, energy and chemicals within the wet dyeing process. Followed by an identification of opportunities for improvements in the wet dyeing process, aiming to become more environmentally sustainable.

Method: Through interviews with two suppliers, information regarding IKEA's current wet dyeing processes will be collected. After that, data from relevant theoretical sources will be collected to analyze possible improvements of methods and colorants that can be relevant for IKEA as well as other companies within the textile industry to implement.

Conclusion: For research question 1, the researchers reach the conclusion that IKEA's supplier number one has a more environmentally sustainable wet dyeing process compared to the second supplier.. A conclusion is nevertheless drawn that improvements within both suppliers wet dyeing processes should be considered to become more environmentally sustainable. For research question 2, the researchers come to the conclusion that Spray dyeing is the best alternative method to implement for improving environmental sustainability within the wet dyeing process. The researchers also recommend companies to actively become a part of the development of bacterial colorants, the future of coloration.

Keywords: Wet dyeing process, Pad-dry-pad-steam, Cold pad batch, Pigment dyeing, Reactive dye, Pigments, Spray dyeing, Foam dyeing, Airflow dyeing, Supercritical carbon dioxide dyeing, Natural colorants, bacterial colorants, environmental sustainability.

Table of content

1. Introduction 5
1.1 Company background 6
1.2 Theoretical background 7
1.3 The problem area 8
1.4 Research questions 10
1.5 Purpose 11
1.6 Disposition 11

2. Research Methodology 12
2.1 Scientific view 13
2.2 Scientific approach 13
2.3 Research method and design 13
2.4 Data collection and interview design 14
2.5 Sample 17
2.6 Research quality criteria 18
2.7 Generalizability 19
2.8 Ethical consideration 20
2.9 Description of the work process 21
2.10 Summary of methodology 21

3. Theoretical background 22
3.1 Wet dyeing process 22
3.1.1 Pretreatment 23
3.1.2 Coloration 25
3.1.3 Finishing 26
3.2 Conventional dyeing methods 26
3.2.1 Pad-dry-pad-steam dyeing method 27
3.2.2 Cold pad batch dyeing method 28
3.2.3 Pigment dyeing method 30
3.3 A summary of the conventional methods impact on environmental sustainability 32
3.4 Conventional colorants used for coloration 32
3.4.1 Reactive dye 33
3.4.2 Pigment 34
3.5 A summary of the conventional colorants impact on the environmental sustainability 35
3.6 Alternative dyeing methods for increased environmental sustainability 35
3.6.1 Foam dyeing method 36
3.6.2 Airflow dyeing method 38
3.6.3 Supercritical carbon dioxide dyeing method (ScCO2) 40
3.6.4 Spray dyeing method 41

3.6.4.1 Imogo 41
3.6.4.2 Combination of wet fixation and dryeing treatment 42
3.7 A summary of the alternative methods impact on environmental sustainability 43
3.8 Alternative colorants for environmentally sustainable coloration 44
3.8.1 Natural colorants 44
3.8.1.1 Archroma's earth colorants 45
3.8.2 Bacterial colorants 46
3.9 A summary of the alternative colorants impact on environmental sustainability 47

4. Empirical data 48
4.1 About the first supplier 48
4.2 The first suppliers wet dyeing process when producing Dvala 49
4.4 Water, energy and chemicals used with the Cold pad batch dyeing method 51
4.5 Supplier one's wet dyeing process using the Pigment dyeing method 53
4.6 Water, energy and chemicals used with the Pigment dyeing method 54
4.7 About the second supplier 56
4.8 Supplier two's wet dyeing process when producing Vågsjön 56
4.9 The wet dyeing process using the Pad-Dry-Pad-Steam dyeing method 57
4.10 Water, energy and chemicals used in the Pad-dry-pad-steam dyeing method 58

5. Analysis 60
5.1 Research question 1: How environmentally sustainable are IKEA's suppliers' wet dyeing process in terms of water, energy and chemicals used? 60
5.2 Research question 2: What improvements could be done in the wet dyeing process to improve environmental sustainability? 64
5.2.1 Water 65
5.2.2 Energy 66
5.2.3 Chemicals 67
5.2.4 Recommended alternative methods 68
5.2.5 Recommended alternative colorants 72

6. Conclusion 75
6.1 Conclusion for research question 1: How environmentally sustainable are IKEA's suppliers' wet dyeing process in terms of water, energy and chemicals used? 75
6.2 Conclusion for research question 2: What improvements could be done in the wet dyeing process to improve environmental sustainability? 76
6.3 The researchers own reflections 76
6.4 Theoretical and practical contribution 77
6.5 Future research 78
6.6 Contribution to society 78

7. Sources 79
7.1 Electronic sources: 79
7.2 Literature sources: 82

8. Appendix **86**
8.1 Interview questionnaire 86

1. Introduction

This chapter contains a description of the thesis' collaborating company, IKEA, the background of the thesis, followed by the problem discussion. After that, the two research questions are presented as well as the purpose of the thesis and at last the disposition.

1.1 Company background

IKEA was founded in Älmhult during 1953, by Ingvard Kamprad. It started as a company selling household products, pens, wallets and picture frames. At this time, it was hard to live in Älmhult and the inhabitants did not have access to a lot of money which resulted in Kamprad wanting to create a company that offered affordable products for the many people. Since then, IKEA has developed into a global furniture business, but they still strive towards the same goal as in 1953, to offer affordable products. This is also one of the reasons behind the company's huge success. Even if a lot has changed since the early days of IKEA, the values and culture within the organization remains the same. IKEA always strives to become better and to find the best solutions. That is reflected in their 8 key values that all employees follows; Togetherness, Caring for people and planet, Cost-consciousness, Simplicity, Renew and improve, Different with a meaning, Give and take responsibility and lastly, Lead by example (IKEA.com, n.d., a).

One further reason behind IKEA's success is the flat packages and the self assembling, which was an idea born in 1956, connected to the launch of the table "Lövet". The flat packages reduce delivery costs since the trucks can be filled with more products which in turn makes it possible for IKEA to keep their prices low and make the products affordable for more people (IKEA.com, n.d., a).

IKEA has multiple direct suppliers followed by several sub-suppliers. To be able to ensure that each supplier within their supply chain comply with IKEA's rules, they created a supplier code of conduct, named IWAY. As IKEA themselves explain, the IWAY is the " IKEA way of responsibly sourcing products, services, materials and components" (IKEA.com, n.d., b). It contains both environmental rules as well as social, both globally and locally. If a supplier does not comply with the IWAY requirements, they will no longer be able to work with IKEA. It is the first tier supplier's responsibility to communicate the IWAY to their sub-suppliers to ensure that the whole supply chain follows the code of conduct. To ensure that all suppliers follow the regulations, IKEA is doing both arranged and unarranged audits. Their goal is to create close and long lasting relationships with all their suppliers and the current average time for a collaboration with a supplier is 11 years (IKEA.com, n.d., b)

IKEA is committed to become a circular business by 2030, including the ambition to use only renewable or recycled material in all products. In addition, IKEA has a global goal to be climate positive by reducing greenhouse gas emissions throughout the supply chain, from raw material until a products' end of life. The total IKEA climate footprint is calculated on a baseline of 2016, with targets set across the globe to enable each entity to contribute towards the common goal. Within all category areas (CA), IKEA targets to reduce the footprint within their direct supplier's productions by -80%, and the raw material footprint by -15% by 2030. Today, the category area Textile Furnishings is responsible for leading and developing textiles across IKEA, in close collaboration with their Home Furnishing Businesses (HFBs), which is developing the final product sold to end customers (IKEA Material and Technology Engineer, 220126).

1.2 Theoretical background

Increasing environmental issues and governmental legal regulations followed by customer awareness, forces businesses towards more environmentally sustainable solutions to be able to stay relevant and competitive. As a company it is more important than ever to consider the environmental aspect within the whole supply chain and all stakeholders. Studies show that people's concerns about the environment increases and will continue to grow in the future. Customers today are more aware of the consequences of their buying behavior and how companies actions can result in destruction of natural resources. As a consequence of this, customers are changing their buying behaviors and are actively trying to improve both companies and governments by raising the environmental sustainability topic. This awareness among the customers creates an expectation on companies to do better regarding the environmental sustainability development. To stay successful as a company, it is therefore necessary to develop environmental sustainability in all stages within the business. That contains everything from the first step where the raw material is purchased to the end where the product reaches the end customer (The economist, 2021).

According to Abbas, Hsieh, Tachato and Taweekun (2020), the textile industry has expanded during the last years, which has a bad impact on environmental sustainability. Jonsson and Mattsson (2016) points out that every step of the textile supply chain is a contributing factor to energy waste and that every step in the supply chain should be investigated if companies want to become more environmentally sustainable. The European Commission (2020) also addresses the issue with the textile production processes and concludes that it is one of the highest-pressure categories of raw materials and water. Therefore, the textile production plan is one of the main tasks in the European commission action plan to create a circular business by 2030.

The wet dyeing process is the part of the textile production that consists of liquor. This process contains three main steps which are pretreatment, coloration and finishing and is presented as one of the most water, energy and chemicals consuming processes. The wet dyeing process uses large amounts of freshwater. For example, it takes about 50 to 100 L water to produce 1 kilogram of textile. The bleaching and dyeing part within the wet dyeing process is contributing to a large chemical waste. Curing and drying the fabric result in high energy usage. Due to the large waste of water, energy and chemicals in the wet dyeing process, this process is important to investigate to be able to improve the environmental impact (Madhav et al., 2018). Uddin (2021) points out that changes must be made in the wet dyeing process to be able to create a large improvement within the textile industry, making it more environmentally sustainable. An example of changes mentioned is to remove methods or colorants that are harmful for the environmental sustainability and replace them with developed and improved versions. Therefore, it is important to look over the wet dyeing processes and what changes that can be made to make it more environmentally sustainable.

1.3 The problem area

There are a lot of different methods and colorants that can be used within the wet dyeing process which makes it complicated to analyze them all for determining the most suitable, aiming to improve the environmental sustainability. With that said, doing research and evaluating the most common conventional methods and colorants as well as new innovations in the market are crucial to make sure that the best wet dyeing process changes are being established. Creating a framework for what methods and colorants to use for improving the impact on environmental sustainability within the wet dyeing process will be helpful for companies when navigating towards a more sustainable production (Khattab, Abdelrahman, Rehan, 2020).

According to Ozturk et al. (2015), the textile industry uses a huge amount of water, energy and chemicals. The production process can be divided into two parts, the wet and the dry process. The dry process includes weaving, drying and knitting etc, which consumes a lot of energy (Ozturk et al., 2015). The wet dyeing process contains pretreatment, coloration and finishing which consumes a lot of water and chemicals, but also energy. Therefore, this study will concentrate on the wet dyeing process and its impact on environmental sustainability since improvements in this process will lead to major developments for the whole textile production industry (Global-standard.org, n.d.). To be able to remain competitive in the textile industry it is necessary to improve the methods and colorants used within the wet dyeing process and make them more environmentally sustainable, which is an increased demand from customers (The economist, 2021).

The thesis will analyze two of IKEA's largest suppliers related to textile production. The research is relevant for further investigation regarding new innovations of methods and colorants to change the wet dyeing process into a more environmentally sustainable process. IKEA is a huge consumer of textiles while they do not know exactly what methods and colorants that their suppliers are producing their products with. Therefore, this thesis will help them understand two of their largest suppliers' current wet dyeing processes and the included methods and colorants, to later on be able to use that as a baseline for further enforcements (IKEA Material and Technology Engineer, 220126). Once these two wet dyeing processes are mapped and analyzed, it is possible for IKEA to further develop the remaining processes within the textile production in order to finally have evaluated and improved the entire production process. It is then also possible for IKEA to implement the improved and preferred methods and colorants to their remaining suppliers.

The thesis will be assigned to two different products, "Dvala " which is a bed sheet produced by supplier number one and "Vågsjön" which is a towel produced by supplier number two. These products are chosen since they are produced by the two chosen suppliers, but also because they are two of the most sold products in IKEA's textile range. The thesis will focus on the water, energy and chemicals used in the two suppliers' conventional dyeing methods and colorants within their wet dyeing processes. That is followed by what changes that could be done to make it more environmentally sustainable. Different suppliers have different approaches on how the textiles are produced, which results in some suppliers having more water, energy and chemical waste than others within the wet dyeing process (IKEA Material and Technology Engineer, 220126). Jonsson and Mattsson point out that one important action to become more environmentally sustainable in the production process is to reduce energy. As a company it is therefore important to look over the suppliers and analyze their production process to see if it can be made in a more environmentally sustainable way (Jonsson & Mattsson, 2016). This thesis will be a starting point, focusing on the wet dyeing process, for further investigation of the whole production process of textiles.

IKEA’s suppliers comply with the IWAY code of conduct and as long as they deliver the bare minimum regarding the environmental sustainability aspect, they can continue working with their current wet production processes (IKEA.com, n.d., b). As a step towards a circular business in 2030, IKEA now wants to look further into the textile production processes from the start to end. This to be able to improve these processes and make the production more environmentally sustainable by reducing i.e the water, energy and chemicals used. To be able to map their supplier’s production processes and how the environment gets affected by it, a lot of communication with the suppliers are required and also access to their data. IKEA is keen to actively become a part of the suppliers' improvements of their production processes and by mapping these processes, it is possible to analyze whether there are possibilities for improvements or not. This thesis will be a part of this development work, focusing on different methods within the wet dyeing process followed by possible improvements. The delimitation to the wet dyeing process is chosen to get a manageable scope that can result in increased and more detailed knowledge of the process within the textile production where most of the water, energy and chemicals are used and how that affects the environmental sustainability (IKEA Material and Technology Engineer, 220126).

1.4 Research questions

- How environmentally sustainable are IKEA’s suppliers' wet dyeing process in terms of water, energy and chemicals used?

- What improvements could be done in the wet dyeing process to improve environmental sustainability?

1.5 Purpose

The purpose of the thesis is to increase the understanding of IKEA’s suppliers' current usage of water, energy and chemicals within the wet dyeing process. Followed by an identification of opportunities for improvements in the wet dyeing process, aiming to become more environmentally sustainable.

1.6 Disposition

Introduction	The background of the thesis will be presented, followed by the problem discussion, research questions and the purpose.

Method	The methodological chapter will present the studies research approach.
Theory	The theoretical chapter will present the studies theoretical frame with second hand sources.
Empirical Data	The chapter will include interviews from two of IKEA's suppliers.
Analysis	The analysis will include answers to the research questions, by comparing the theoretical framework and the collected empirical data.
Conclusion	The conclusion will answer the research questions asked in the introduction. The researchers' own reflection, theoretical and practical contribution, suggested future research and the contribution to society is also presented in this chapter.

Table 1: Disposition

2. Research Methodology

This chapter contains the methodological approach that is used to collect information regarding IKEA's current wet dyeing process. Followed by the data collection needed to analyze possible improvements of methods and colorants that can be relevant for all companies within the textile *industry to implement.*

2.1 Scientific view

The scientific view refers to how to define valid truth (Bryman & Bell, 2017). The scientific view that this thesis is conducted with is critical realism, which Bryman and Bell (2017) explains as an identification of underlying structures to be able to understand and change a phenomena. It also points out that the researcher can collect knowledge from different places and that the researcher's perception is only one way to collect it. The researchers collected information and knowledge directly from the two chosen suppliers as well as from their supervisor at IKEA, working as a Material and technology engineer. The researchers are also collecting information and improving their understanding of underlying structures within the suppliers' different conventional dyeing methods and colorants, to be able to present changes and improvements in their current wet dyeing processes.

2.2 Scientific approach

The thesis has a deductive approach which Bryman and Bell (2017) describes as a research guided by theory. The theory will be the starting point to later on collecting empirical data. The empirical data collected will then be compared with the theory, for the researchers to discover if there are any differences or not, and be able to answer the research questions. Theory regarding both conventional and alternative methods and colorants within the wet dyeing process will be the starting point, to increase the researchers knowledge within the field. After that, the empirical data will be collected from the two chosen suppliers containing information about their currently used conventional methods and colorants usage of water, energy and chemicals within the wet dyeing process, which later on will be compared with the theory founded. It makes it possible to detect possibilities for improvements that could be worth implementing to make the wet dyeing process more environmentally sustainable.

2.3 Research method and design

According to Bryman and Bell (2017), a research method can be either quantitative or qualitative. The quantitative research method has a more siencefical approach and is based on answers from collected data, so the answers should not be interpreted. The qualitative research method on the other hand has a more interpreted approach. The researchers therefore need to interpret the answers to get a better view over the participants' thoughts and opinions. In the qualitative research method, the empirical data and research are also connected to relevant theory (Bryman & Bell, 2017).

The thesis is using a qualitative research method since the data are going to be collected from interviews with two of IKEA's suppliers as well as from theoretical sources. The researchers are then going to analyze and interpret the answers given, to get an overview of how different methods and colorants contribute to the usage of water, energy and chemicals within the wet dyeing process.

2.4 Data collection and interview design

The thesis includes both primary data and secondary data which means that some data are collected through interviews and some other data are collected by other researchers. The primary data in the thesis is collected by the researchers through structured interviews with two chosen suppliers, focusing on the water, energy and chemicals used in their wet dyeing process (Bryman & Bell, 2017). The primary data collected are the conventional methods and colorants that are currently used by two of IKEA's largest suppliers. This data collection will increase the researchers knowledge about how two suppliers to one of the biggest furniture companies in the world, IKEA, are using water, energy and chemicals within their wet dyeing process. A collaboration with IKEA was chosen since they are huge consumers of textiles and work together with large suppliers. They are also working with environmental sustainability in all category areas and are in the middle of developing more in-depth information regarding waste in the production process of textiles.

For the researchers to be able to find relevant theoretical material, secondary data was collected through scientific articles, containing transcribed interviews and statistics that the researchers analyzed. Besides that, also relevant electronic sources were used to be able to get the desired information. Scientific articles were used as far as possible, but in the theoretical section where each chemical within the conventional methods and its impact on environmental sustainability are explained, few relevant studies have been made. Therefore, the researchers also used other electronic sources to be able to present all relevant information needed for further analysis regarding its impact on environmental sustainability. The reason why each chemical within the conventional methods were described in the theoretical chapter, but not each chemical used for the improved alternative methods depends on the conventional methods belonging to research question 1 which is specified to the water, energy and chemical usage. The improved, alternative methods belong to research question 2 and contain more general theoretical information regarding their impact on environmental sustainability and how they can improve it by replacing conventional methods. Secondary data requires a control of the quality of the data to be able to use and trust it. The secondary data collected were therefore valued on four quality criterias presented by Bryman and Bell (2017) which are authenticity, credibility, representativeness and meaning.

Bryman and Bell (2017) presents two different ways of interviewing; semi-structured and structured interviews. The former refers to the person getting interviewed having some freedom to answer the question as he or she wants to, with the risk of losing track of the purpose with the question. The second interview design means that there are more clear frameworks regarding the questions as well as the answer, aiming to increase validity and reliability. The data collected through structured interviews were the use of water, energy and chemicals in two of IKEA's key textile suppliers' wet dyeing processes. Initially, the suppliers received a questionnaire with specific questions, for them to be able to prepare the answers they presented in the following interview with the researchers. The interview with supplier number one were held digitally through Teams and answers were received from a production engineer and a manager with specialization within product development. For the researchers further questions, information was received through email, answered by the two persons that participated in the first interview. The interview with the second supplier were held through email by their Sales team leader and the information was collected from himself and one of their production engineers.

Semi-structured interviews were arranged for the researchers to increase their knowledge about the product category area "Textile furnishing" and IKEA's internal work. This information was received during digital weekly meetings with the researcher's supervisor at IKEA, working as a "Material and Technology Engineer". The supervisor was also the one connecting the researchers with the two chosen suppliers. Additional information about IKEA and their textile category area were received through a visit to the IKEA office in Älmhult where the researchers got the possibility to look into ongoing product developments within the textile area.

Data collection

Date	Location	Data collection	Present	Time	Purpose of meeting
12/1-22	Teams	Semi-structured interviews	Material & Innovation area Manager and Material & Technology Engineer at IKEA	1h	Introduction of thesis
17/1-22	Teams	Lecture	IKEA's thesis students	2h	Intro for thesis students
24/1-22	Teams	Lecture	IKEA's thesis students	2h	Placeholder - Onboarding session CA Textile Furnishings
26/1-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	1h	Introduction of the production process
28/1-22	Teams	Lecture	IKEA's thesis students	2h	Code of conduct
2/2-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	Different techniques of the dyeing process
9/2-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	Different techniques of the dyeing process
16/2-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	45 min	Questions to the suppliers
24/2-22	Teams	Semi-structured interviews	Production Engineer for the first supplier	2h	Answers on questionnaire
21/3-22	IKEA in Älmhult	Workshop	Employees at IKEA and thesis students	4h	Mid-presentat ion
31/3-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	Discussion of the second answers from the first supplier

13/4-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	General questions
20/4-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	General questions
27/4-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	15 min	General questions
04/05-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	General questions
11/05-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	30 min	General questions and discussion about the second supplier
17/05-22	Teams	Semi-structured interviews	Material & Technology Engineer at IKEA	45 min	Discussion about the questions to supplier two

Table 2: Data collection

2.5 Sample

According to Bryman and Bell (2017), a sample is used to minimize the intake of information used in a study. It is harder to collect information from a whole population than from a selected group of people. There are two different types of samples, probability sample and non-probability sample (Bryman & Bell, 2017).

Probability samples are an important method to get a trustworthy result. The approach is to do the sample on a random basis, which means that everyone in a population could be selected. The non-probability samples are hand picked groups from the population and the methods are usually used in qualitative surveys. This thesis is based on a qualitative survey which makes the sample non-probability. There are three different types of non-probability samples which are convenience sample, quota sample and snowball sample (Bryman & Bell, 2017).

The thesis is based on a snowball sample. The snowball sample means that the researchers selects people that are relevant for the study, for them to further support the researchers to proceed with new meaningful people that are relevant for the thesis (Bryman & Bell, 2017). The researchers have a supervisor at IKEA connecting them to relevant contacts and sharing useful information. Further on, the first research question of the thesis is based on two different suppliers, producing two different products for IKEA. The first supplier is located in Pakistan and produces the bed sheet Dvala, which is one of the most sold products within IKEA's textile range. The second supplier that is a part of the thesis is located in India. They are producing the product Vågsjön which is a towel and like Dvala, it is one of the most sold products within the textile range. Both suppliers have long term relationships with IKEA in combination with producing large volumes of products. Analyzing these two suppliers and their usage of water, energy and chemicals within the wet dyeing process of the products Dvalan respectively Vågsjön will result in IKEA increasing their knowledge about two of their biggest suppliers' impact on environmental sustainability. That will also create possibilities for improvements that further on can be implemented in more suppliers than just these two that are included in this thesis.

2.6 Research quality criteria

According to Yin (2018), there are four different tests to ensure quality of the research design. The first test explains the construct validity and is important in case studies where criticism is applied. The test helps to prove that the information collected in the study is trustworthy. To prevent the researchers from having a subjective judgment, a conducting validity test is important and a solution is to use different sources that back each other up (Yin, 2018). In the majority of the thesis, the sources are backed by each other, with some exceptions where several different sources were not found. These exceptions include information that are not crucial for the thesis' conclusion, e.g how each chemical affects the environmental sustainability. The lack of sources regarding each chemical made it impossible to back up multiple sources with each other.

The second test that Yin (2018) mentions is internal validity. The internal validity is important to use in explanatory case studies and fails if the researchers do not have knowledge about all the variables. To prevent the internal validity to fail, pattern matching of the variables using logical models is a solution (Yin, 2018). The researchers therefore have a relatively even balance between the theoretical data and the empirical data in the thesis. Since the second research question contains improved, alternative methods and colorants which are not used by any of the suppliers of the collaborating company, no empirical data were collected. Instead, the second research question is based on theoretical sources that later on are evaluated against and compared with conventional methods and colorants, which is based on both empirical data and theoretical data.

The third test that is mentioned by Yin (2018) is external validity. External validity means that the findings of the study can be generalizable to other people and situations and is applicable in a wider context. To obtain external validity it is important to choose the right people to take part in the study (Yin, 2018). The researchers have collected information from chosen employees from IKEA and from two of their key suppliers. The suppliers chosen are large companies within the textile industry and are producing products to IKEA as well as other textile companies that are selling to end customers. Taking their knowledge and information into the thesis results in increased external validity since it can be applied to other companies within the textile industry as well.

The last test that Yin (2018) talks about is reliability. Reliability means that if the researchers use the same methods and working process as another researcher, the result of the study should be the same. To be able to test this, a study protocol could be used (Yin, 2018). The researchers are showing the procedure of the thesis work by sharing how the data was collected, who was interviewed and what techniques were used to collect the relevant information and data. In that way, the reliability and the possibility for another researcher to receive the same information when following the same procedure, increases.

2.7 Generalizability

Bryman and Bell (2017) discuss the issue regarding the generalizability of a specific case study since it is difficult to create an overall picture from one single case and its result. They also describe two types of generalizability which are analytical and statistical generalizability. Analytical generalizability means that the theory is tested against the result of the study to analyze if there are any correlation or not. The statistical generalizability draws conclusions directly from the empirical data collected in the study (Bryman & Bell, 2017).

This thesis is based on analytical generalizability since the starting point is the theory that presents and compares different dyeing methods and colorants within the wet dyeing process. This is later on connected with the empirical data collected. The first research question is specific for the collaborating company IKEA where two of their key suppliers' conventional methods and colorants within the wet dyeing processes are explained, in terms of water, energy and chemicals. From a generalizability perspective, that information could be interesting for companies using the same conventional methods as IKEA, to be able to compare their water, energy and chemical usage with them, with the possibility to find suggested improvements to their own wet dyeing process. The discussion and findings related to the second research question will be applicable and relevant for all companies within the textile industry since it presents new methods and colorants within the wet dyeing process that possibly could improve their impact on the environment sustainability.

2.8 Ethical consideration

Ethical considerations are principles guiding the researcher's way of working and are important in all aspects of a research (Bryman & Bell, 2017). This thesis is based on a collaboration between the researchers and IKEA that has shared relevant information and expertise related to the purpose of the thesis work. For the collaborating company to be able to share this confidential information to the researchers, a confidentiality agreement was signed by the researchers, the supervisor at IKEA and the supervisor at Linnaeus University, before the collaboration started. This contract means that the researchers have restrictions to follow to be able to guarantee confidentiality of the information acquired from the company. Another ethical consideration is the sensitive handling of IKEA's inputs through constant communication with the supervisor, for the researchers to get knowledge about what data and information that has to be excluded from the manuscript.

2.9 Description of the work process

The work process in the thesis has been divided equally between the researchers. In the methodology chapter, the researchers begin to discuss what methodology is the most reasonable for the thesis and later the researchers divided the writing of the methodology equally. For the theoretical chapter, the researchers divided the work equally when searching for literature sources such as scientific articles, as well as the electronic sources. Keywords that was being used when searching for scientific articles were; Wet dyeing process, Pad-dry-pad-steam, Cold pad batch, Pigment dyeing, Reactive dye, Pigment, Spray dyeing, Foam dyeing, Airflow dyeing, Supercritical carbon dioxide dyeing, Natural colorants, Bacterial colorants and environmental sustainability. Both researchers have been a part of the interviews with the two suppliers as well as all interviews and lectures that IKEA has provided. During the interviews, the researchers divided the work between each other so that one of them took notes while the other asked the questions. The analysis and the conclusion were also divided equally between the researchers to be able to reach the best conclusion possible, which they both contributed to.

2.10 Summary of methodology

Scientific view	Critical realism
Scientific approach	Deductive approach
Research method and design	Qualitative research method
Data collection and interview design	Primary data, secondary data, semi-structured interviews and structured interviews.
Sample	Non-probability sample, more precisely snowball sample
Research quality criteria	Construct validity, external validity, internal validity and reliability
Generalizability	Analytical generalizability
Ethical consideration	Collaboration between the researchers and a company

Table 3: Summary of methodology

3. Theoretical background

This chapter contains the theoretical background for the research questions. The chapter starts with an explanation of the wet dyeing process continued by the conventional methods and colorants, which is the ones currently used by IKEA. After that, alternative methods and colorants are presented, which are improved methods and colorants regarding their impact on environmental sustainability, especially in terms of water, energy and chemicals usage.

3.1 Wet dyeing process

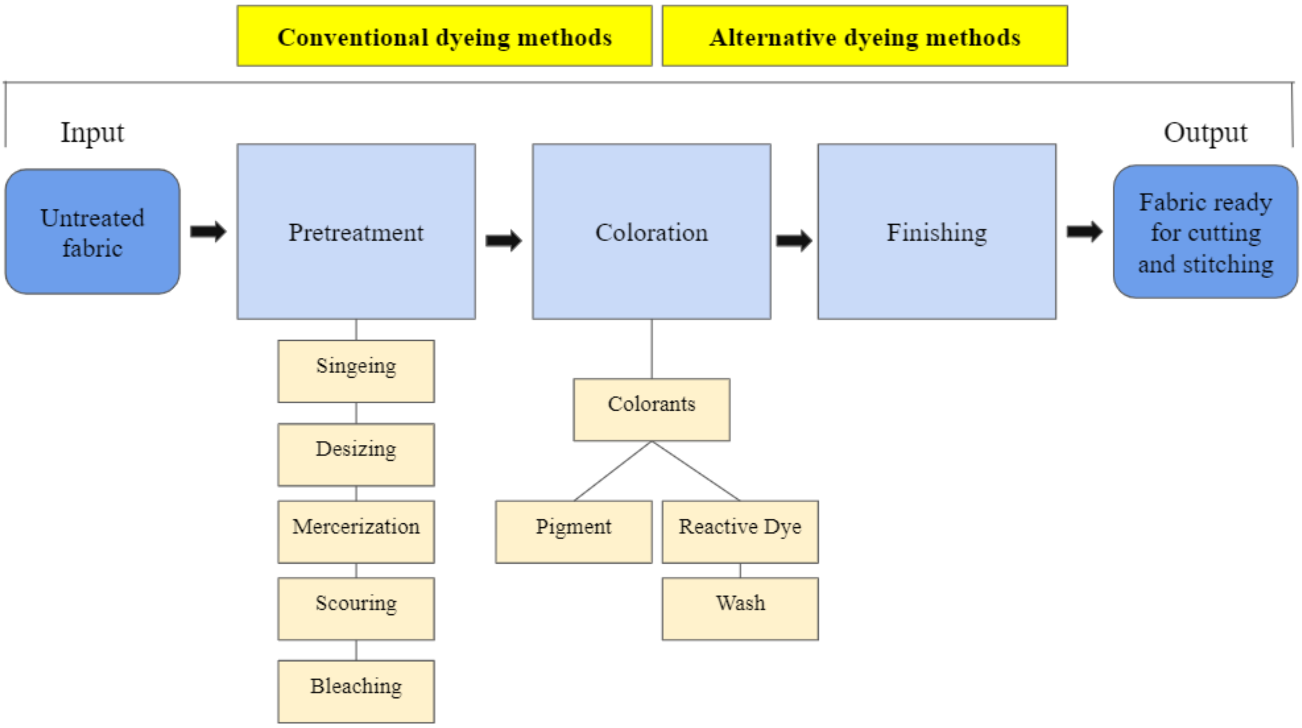

Figure 1: Wet dyeing process

The thesis is based on the wet dyeing process, meaning the sections within the process of textile production that contain liquid. Each step included in the wet dyeing process is presented in figure 1 which is pretreatment, coloration and finishing. These sections can differ depending on which dyeing method that is used or what machines that the producer has invested in. However, the basic principle remains the same, even if different methods for example apply the colorants on the fabric differently or if it is an older, conventional method or a newer, alternative method (Textilelearner.net, a, 2021).

3.1.1 Pretreatment

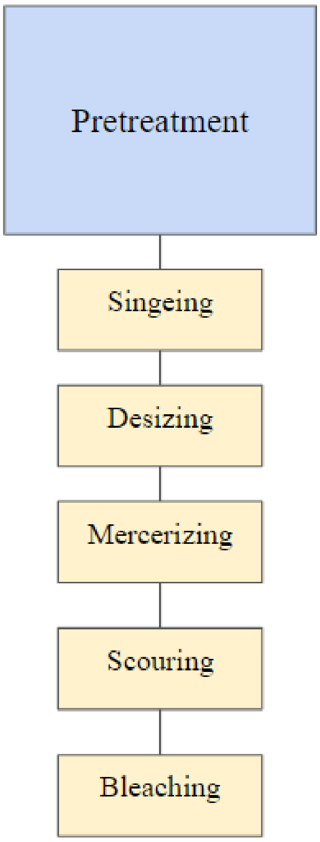

Figure 2: Wet dyeing process, pretreatment

Fabric pretreatment is made through following steps: Singeing, desizing, mercerizing, scouring and bleaching. The singeing is made to remove the surface fibers through a gas flame. It is made since these fibers tend to disturb the surface of the fabric and result in uneven finish when being dyed. After going through a gas flame, the fabric is going into a bath to remove the sparks and cool the fabric (European commission, 2003).

Desizing is used for removing the sizing agent that is applied on the fabric during the yarn preparation, which is the last step before the wet process starts. Starch is applied to the yarn to give it more strength and in that way reduce the risk of destroyed yarn in further processes. The most common sizing agent is starch-based which is difficult to remove. To be able to remove it, either chemicals or enzymes are required. Enzymatic desizing is the most common removal of starch with the advantage of not damaging the cellulose fiber (European commission, 2003). The preferred type of enzyme is amylases since they are able to cleave starch particles into water soluble components that are possible to wash off. Amylases are hydrolase enzymes which means enzymes that enable cleaving a covalent bond through water usage (Mojsov et al. 2018).

To be able to reduce the number of steps in the pretreatment process, it is possible to combine desizing with cold bleaching, which is called “Oxidative desizing”. This process contains the fabric getting immersed in a bath of hydrogen peroxide, caustic soda, complexing agents and persulphate (European commission, 2003).

Mercerization creates strength and dimensional stability in the fabric, in combination with improved dye uptake. Mercerization is made through the fabric getting treated in a solution of caustic soda under tension. To be able to ensure a penetration of the color, a wetting agent is used (European commission, 2003).

Scouring is made to make the fibers suitable for following processes. It includes boiling the textile with alkaline which eliminates impurities, e.g pectin. In the following neutralization, a lot of wash effluent that contains harmful chemicals is generated. Scouring can be done with enzymes which reduces the usage of water and chemicals as well as energy. That is because this type of reaction only requires mild temperature and pH conditions. Increasing enzyme concentration increases the bioscouring efficiency (Varadarajan and Venkatachalam, 2015). According to Nielsen, using 10 kg of enzymes instead of alkali process, can save up to 20 000 kg water per tonne of yarn (Nielsen, 2009).

The last step in the pretreatment is bleaching which is made to remove hints of darker spots on the fabric that might be visible in lighter colors. Fabric with darker shades can also be convenient to bleach, to get a desired surface as a baseline before dyeing. The most common for cellulosic fibers are oxidative bleach, e.g hydrogen peroxide which is a climate friendly alternative since it is naturally-occuring (European commission, 2003).

3.1.2 Coloration

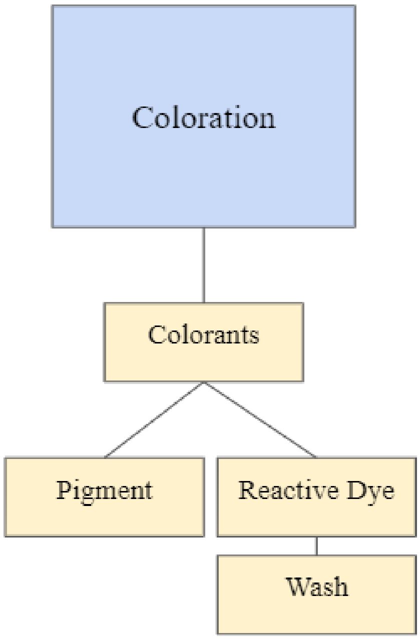

Figure 3: Wet dyeing process, coloration

The second step in the wet dyeing process is the “coloration” which is the process where a colorant is applied on the fabric to get the desired color. The coloration can either be done using pigments or dyes, depending on the fabric and what method that is most suitable. The dye is applied on the fabric in a uniform manner to obtain an even shade on the fabric. How the color is applied on the fabric can differ from method to method. In some methods, washing is included after the fabric has been dyed while other methods do not include washing. The reason why some methods need to wash off the fabric after coloration depends on the fabric still having excess chemicals that are not good to have in the finished product (European commission, 2003).

3.1.3 Finishing

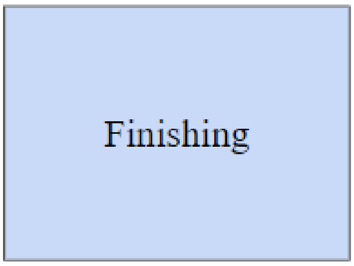

Figure 4: The wet dyeing process, finishing

The last step of the wet dyeing process is called "finishing" and appears after the fabric has been colored. Finishing refers to the process that converts the fabric into usable material, i.e how the fabric looks and feels as well as the performance of the fabric. The finishing step is important for the fabric to later on be useful and ready for sale (Madhav, Ahamad, Singh and Mishra, 2018).

3.2 Conventional dyeing methods

Conventional dyeing methods are the ones that have been on the market for a longer time and used by many companies in the textile industry, including IKEA. They are used since they fulfilled the requirements that companies were looking for in a dyeing method. But as Kerle et al. (2021) presents, the world and society is changing and these methods therefore need to be reviewed for companies to find possible replacements where it is needed for becoming more environmentally sustainable.

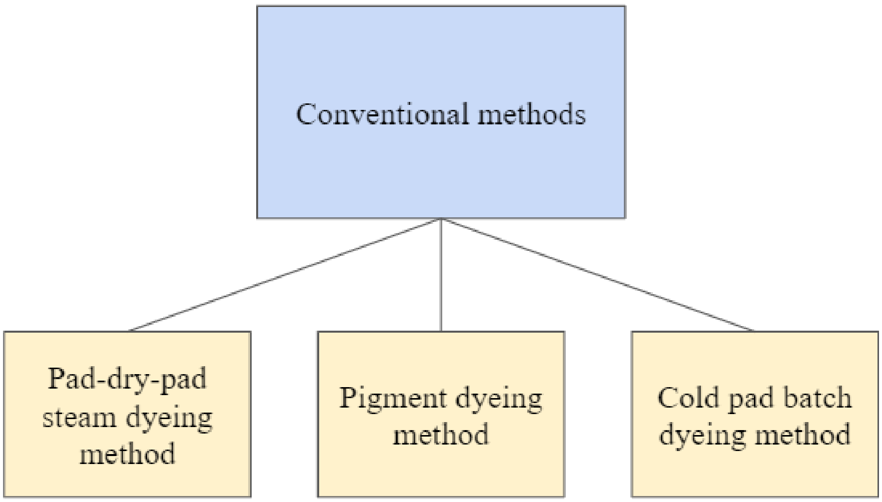

Figure 5: Conventional methods

3.2.1 Pad-dry-pad-steam dyeing method

Pad-dry-pad-steam is an effective method that starts with the fabric initially getting immersed in a prepared dyeing solution that contains reactive dye and alkali. Then the fabric is passed through a vertical two-roll padder and is immediately dried with a hot-air machine for fixation. The fabric is then immersed in a prepared dyeing solution that consists of sodium chloride and soda ash, then the wet fabric is steamed. All the dyed fabric is later washed first with cold water and then with hot water and lastly will the fabric be dried (Yu, Xi, Lu, Tao and Yi, 2020).

The Pad-dry-pad-steam method is using a high consumption of energy due to the intermediate drying. But it is not only the energy waste that is problematic for this method. Also heavy discharges of inorganic salts, unfixed dyes and alkalis are being released to the effluents which is not good for the environment. Therefore, this method is not the best from an environmentally sustainable point of view (Zhang, Fang, Zhang, Shu, Gong and Liu, 2017).

Chemicals used in the process	impact on environmental sustainability
Synthetic petrochemicals	Not environmentally sustainable since it contributes to air and water pollution. *(Sciencing.com)*
Alkali	Not environmentally sustainable, but not extremely toxic for the environment. *(Mendes et al., 2021)*
Sodium chloride	Not environmentally sustainable since it can have a bad impact on aquatic environments in high concentrations. *(European commission, 2003)*
Soda ash	Environmentally sustainable since it is naturally occuring. *(Products.pcc.eu)*

Table 4: Chemicals used in Pad-dry-pad-steam dyeing method

An overview of the Pad-dry-pad-steam dyeing method's water, energy and chemical use

Method	Water	Energy	Chemicals
Pad-dry-pad-steam dyeing method	A lot of water is needed in the washing processes because of the usage of reactive dye. *(Yu, Xi, Lu, Tao and Yi, 2020)*	A high consumption of energy due to the intermediate drying. *(Zhang, Fang, Zhang, Shu, Gong and Liu, 2017)*	A lot of chemicals are used. *(Zhang, Fang, Zhang, Shu, Gong and Liu, 2017)*

Table 5: An overview of the Pad-dry-pad-steam dyeing method's water, energy and chemical usage

3.2.2 Cold pad batch dyeing method

Cold pad batch is a discontinuous method using reactive dyes, which means that chemicals are used to react with the fiber to form a covalent bond. Discontinuous process refers to a production that is divided in different steps and machines where the fabric is taken from one machine to another throughout the whole production process from start to end. The Cold pad batch method starts with the fabric being padded in a padding mangle with reactive dye and alkali which is included to get color fixation. The fabric is after that rolled into a batch containing polyethylene sheets wrapped batches where the fabric is stored between 1-24 hours in a cold temperature between 20-30 degrees celsius. During the time in the batch, the fabric will be kept rotating to reach the best color possible. After these 1-24 hours, the fabric is washed in a machine to remove the unfixed dye. After that, the fabric is treated in a machine for finishing, leaving it with a desired surface (Geberehiwot and KA, 2020).

The Cold pad batch dyeing method is more environmentally sustainable than the rest of the conventional methods using reactive dyes, e.g Pad-dry-pad-steam, because of its reduced use of water, energy and chemicals in combination with removed salt from the effluent. The reduced energy usage is because this method handles the fabric in a cold temperature. The reason why there is less water needed compared to other conventional methods using reactive dyes is because of the low liquid ratio. The reason why the amount of chemicals needed are reduced is because the dye is optimally utilized compared to other conventional methods using reactive dyeing. That results in less chemicals needed to create the desired color finish on the fabric (Geberehiwot and KA, 2020).

The method also results in high dye fixation. Since it is a method using reactive dyes, chemicals are still needed in the dyeing process and therefore also the washing process afterwards. The amount of time that is needed for this method makes it less attractive to businesses aiming for a high production rate. Another issue is that it can be difficult and time consuming to achieve the same color in different batches which can result in all products within the same customer order not being colored in the exact same shade (Khatri, Hanif Memon and Tanwari, 2011).

Chemicals used in the process	impact on environmental sustainability
Alkali including Caustic soda	Not environmentally sustainable since it reduces the acidity in the water. *(Foodprocessing.com)*
Hydrogen peroxide	Environmentally sustainable since it is naturally occuring. *(Barnhardtcotton.net)*
Urea	Not environmentally sustainable since it acts as undesired fertilizer and can result in algal blooms. *(Wateractionplan.com)*
Soda ash	Environmentally sustainable since it is naturally occuring. *(Products.pcc.eu)*

Table 6: Chemicals used in the Cold pad batch dyeing method

An overview of the Cold pad batch dyeing method's water, energy and chemical use

Method	Water	Energy	Chemicals
Cold pad batch dyeing method	Less water than other conventional methods using reactive dye due to low liquid rate. *(Geberehiwot and KA, 2020)*	Less energy use than other conventional methods using reactive dye since it is a cold process. *(Geberehiwot and KA, 2020)*	Lower chemical use than other conventional methods using reactive dye since the dye is optimally utilized. *(Geberehiwot and KA, 2020)*

Table 7: An overview of the Cold pad batch dyeing methods water, energy and chemical usage

3.2.3 Pigment dyeing method

Pigment dyeing is a method where pigments are applied on the surface of the fabric where no chemical reaction between the fabric and the dye takes place. The Pigment dyeing process passes the fabric through a bath including pigments and a binder. After that, the fabric is dried and cured at a temperature between 140-150 degrees celsius during 3-5 minutes (Chakraborty, 2014).

This method contains characteristics that are both beneficial and non beneficial for environmental sustainability. One of the beneficial characteristics of this method is that it uses a lot less water than conventional methods using reactive dye since pigments are water insoluble and no chemicals need to be washed off. Instead, the pigment gets stuck on the surface of the fabric. The method also results in less chemicals needed because of the elimination of the aftertreatment where the dye is washed off. Instead, in Pigment dyeing there are binders required in the dyeing process to be able to reach the best possible colorfastness. Using pigments also results in this method being cheaper than conventional methods using reactive dyes. At the same time, it is also a relatively uncomplicated method that excludes complications (Chakraborty, 2014).

The characteristics of this method that is not beneficial for the environmental sustainability is that it results in higher energy usage than conventional methods using reactive dyes because of the curing process. Beyond that, other disadvantages with the Pigment dyeing method is that it is only possible to produce light shades and not dark or deep colors. It can also be difficult to apply on all types of fabric since the pigments are only getting applied on the surface of the fabric instead of creating a covalent bond. That results in an increased risk of the color fading and changing (Chakraborty, 2014).

Organic pigments

Chemicals used in the process	impact on environmental sustainability
Azo	Environmentally sustainable *(Persistencemarketresearch.com, 2021)*
Phthalocyanine	Relatively environmentally sustainable since it is non toxic. *(Wikipedia.org, 2021)*
Quinacridone	Environmentally sustainable since it is based on renewable material. *(Clariant.com, 2022)*
Isoindoline	Environmentally sustainable since it is an organic compounding. *(Hou, Sun, Jiang and Zhang, 2020)*

Table 8: Pigment dyeing method, organic pigment

Inorganic pigments

Chemicals used in the process	Impact on the environmental sustainability
Metallic oxides	Not environmentally sustainable since it is highly toxic. *(Zhu, Wu, Chen, Liu, Xiong, Wang, and Wang, 2019)*
Hydroxides	Different types of Hydroxides affect the environment in different ways but overall, it does not have a major impact on environmental sustainability. *(Corporate.evonik.com, n.d.)*
Chromates	Not environmentally sustainable since it is highly toxic (*Farris, 2014)*

Table 9: Pigment dyeing method, inorganic pigment

An overview of the Pigment dyeing method's water, energy and chemical use

Method	Water	Energy	Chemicals
Pigment dyeing method	Lower water consumption compared to all other conventional methods because no chemicals are washed off. *(Chakraborty, 2014)*	Higher energy usage than methods using reactive dyeing because of the curing process. *(Chakraborty, 2014)*	Low chemical use because the reduction in finishing where e.g washing takes place. *(Chakraborty, 2014)*

Table 10: An overview of the Pigment dyeing method's water, energy and chemical usage

3.3 A summary of the conventional methods impact on environmental sustainability

The conventional methods' impact on environmental sustainability

Conventional method	Positive impact on environmental sustainability	Negative impact on environmental sustainability
Pad-dry-pad-steam dyeing method	No positive impact on environmental sustainability compared to other conventional methods	High consumption of energy due to the intermediate drying. Large consumption of water due to reactive dyes and chemicals needed to be washed off. Heavy discharges of inorganic salts, unfixed dyes and alkalis are being released to the effluents.
Cold pad batch dyeing method	Reduced use of water compared other conventional methods using reactive dyes due to reduced liquid ratio. Reduced use of energy compared to other conventional methods using reactive dyes due to a cold process. Reduced use of chemicals compared to other conventional methods using reactive dyes due to optimal dye utilization.	Discharges of unfixed dyes and chemicals are being released to the effluents. Relatively large consumption of water due to reactive dyes and chemicals that need to be washed off.
Pigment dyeing method	Large reduction of water compared to all conventional methods using reactive dyes. Uses less chemicals than all conventional methods using reactive dyes.	Risk of the color changing and fading, resulting in additional waste of energy, water and chemicals Requires higher energy usage than conventional methods using reactive dyes due to the curing process.

Table 11: The conventional methods impact on environmental sustainability

3.4 Conventional colorants used for coloration

The conventional colorants are the ones being on the market for a longer time and used by companies within the textile industry, including IKEA. As Kerle et al. (2021) communicates, the world and society is changing and these colorants therefore need to be reviewed for companies to find possible replacements where it is needed for becoming more environmentally sustainable.

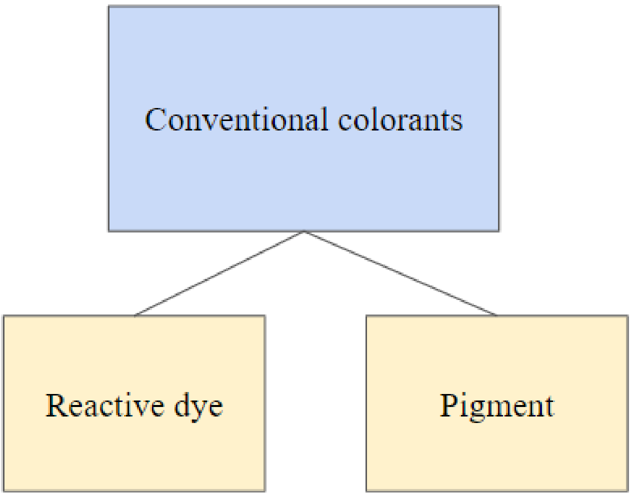

Figure 6: Conventional colorants

3.4.1 Reactive dye

Reactive dye is water soluble and later on in the process needs to be washed off. The dye stuff includes a reactive group that reacts chemically with fiber molecules and creates a covalent bond. The bond is created through the reactive group and hydroxyl of cellulosic fiber. This coloration can be used on a lot of different materials, i.e cotton, wool fibers and silk. The range of colors possible is large, with a variety from light to heavy dark shades. Dyeing methods using reactive coloration require less time than other methods and are also seen as relatively simple methods (Textilelearner.net, b, 2021).

The assistants used in the coloration process with reactive dyes are salt, alkali, urea and soaping. The salt increases the affinity of dye to fiber. Alkali are required to keep a proper pH in the dyeing batch which is between 10-12,5. Alkali is used to fix the dye and without it, no coloration will take place. Darker colors require more urea and lighter colors require less. It is used to increase the dye solubility and is not good from an environmental sustainability perspective (core.ac.uk, 2010).

Soaping removes the extra dye stuff from the surface of the fabric and improves the stability and brightness of the dye (Textilelearner.net, c, 2021).

Reactive dye results in excellent color fastness through the covalent bond that is formed between the fabric and the dye molecules (El-Molla, Haggag and Mahmoued, 2015). It is also applicable on all types of fabric. Reactive dyes result in large consumption of water in the process where the dye stuff needs to be washed off, which has a negative impact on environmental sustainability (El-Molla, Haggag and Mahmoued, 2015).

3.4.2 Pigment

Pigments are coloring materials that do not need to react with textile fibers to stick to the fabric. Pigments can be both organic and inorganic. There are three types of organic pigments, Carbon pigments, Lake type pigments and Non-ionic organic pigments.
The pigments are applied through a thickening system together with a binder and acidic catalyst. The binder reacts with the fibers which results in the pigment getting stuck between the fabric and the binder. The larger the particles are, the better coverage and light fastness will appear on the fabric, but the consequence for that is the decreasing color strength (Chakraborty, 2014).

Pigment is applicable on all materials and after being applied on the surface, it is not washed off, since it is water insoluble. That results in less water consumption and less wastewater related to the coloration process. But it also leads to one of the biggest issues related to pigments, that they are not resulting in as good colorfastness as reactive dye. The second disadvantage with the colorant is that a lot of energy is required for the pigment to get stuck on the fabric through curing (Chakraborty, 2014).

Pigments are insoluble and do not require a washing process after being applied on the surface of a fabric. It is therefore seen as better than reactive dye from the water consumption perspective (Gürses, Acikyldiz, Günes and Gürses, 2016). Pigments can be classified in two categories, organic and inorganic. Examples of organic pigments are Azo, Phthalocyanine, Quinacridone and Iso-indoline. Inorganic pigments are metallic oxides, hydroxides and chromates (Textilelearner.net, d, 2021).

3.5 A summary of the conventional colorants impact on the environmental sustainability

The conventional colorants' impact on environmental sustainability

Colorants	**Positive impact on environmental sustainability**	**Negative impact on environmental sustainability**
Reactive dye	Results in excellent colorfastness which eliminates the risk of needing to redo the wet dyeing process. Requires less energy than pigment since the reactive dye gets stuck on the fabric through a chemical reaction.	Contains a lot of chemicals. Needs to be washed off the fabric.
Pigment	Organic pigment choices available. Do not need to be washed off the fabric, reducing the water usage.	Inorganic pigments are negative for environmental sustainability. Requires more energy than reactive dye for getting stuck on the fabric, due to curing.

Table 12: The conventional colorants impact on environmental sustainability

3.6 Alternative dyeing methods for increased environmental sustainability

An alternative dyeing method is a new or improved method that can replace the conventional ones. The colorants presented in this chapter are chosen since they indicate to be more environmentally sustainable than the conventional ones in terms of water, energy and chemicals.

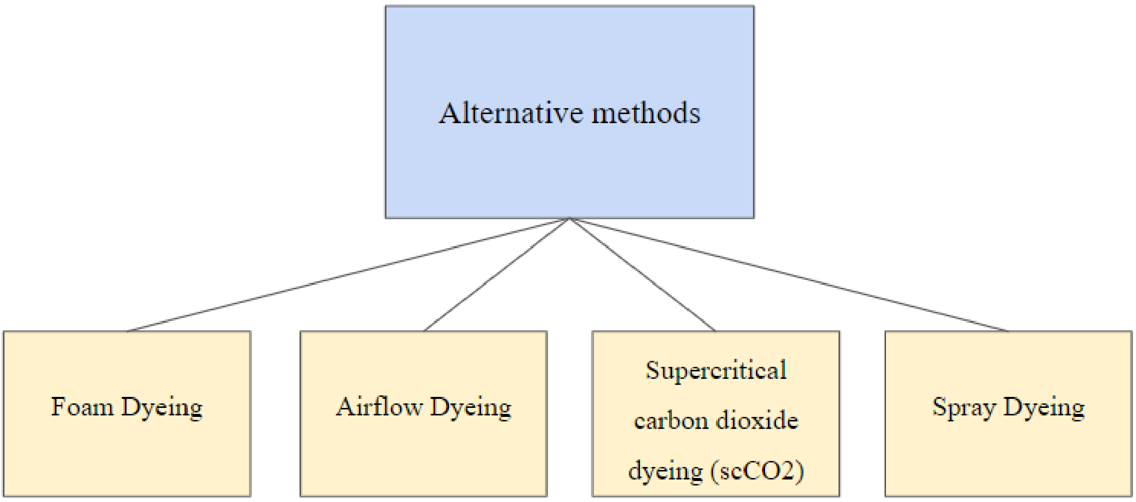

Figure 7: Alternative methods

3.6.1 Foam dyeing method

Foam dyeing means that foam is used to carry the dyes over the fabric instead of water as in other methods. The method reduces the use of water and energy since the water is replaced by air. A study made by Yu, Wang, Zhong and Mao (2014) shows that the water consumption is 300 kg/ton when using the Foam dyeing method while conventional dyeing methods uses 1600 kg water for the same amount of fabric. The electricity is also reduced and the study shows that 23,54 kWh are used for 1 ton of fabric with Foam dyeing compared to 122,29 kWh for the same amount with conventional dyeing methods. Foam dyeing also reduces the drying time and mitigates the chemical used. Compared to conventional Pad dyeing, the use of chemicals is much lower in Foam dyeing. With conventional pad dyeing means all dyeing methods where the fabric is colored by passing it between a roller. E.g the methods Cold pad batch and Pad-dry-pad-steam. Another advantage with the Foam dyeing technique is that it also allows one sided treatment which decreases the use of dyeing required (Yu et al., 2014).

The first step within Foam dyeing is the pre-washing to remove dirt from the fabric. The second step involves soda ash that is dissolved in hot water where the fabric is soaked in for around 5 to 10 minutes and then dried. The third step is that dye powders are mixed and stirred together with warm water. After that, the foaming agent is added and blended until it has a creamy and thick texture. Then the mixture is poured into a tank where a tool is spreading the dye and also removes air bubbles. Afterwards, the fabric is dried for a couple of minutes (Fashinza, n.d.).

Foam dyeing is seen as a good choice both from a financial and sustainability perspective. The method uses minimal water which also decreases the energy use. It is also applicable on all types of fabric and all types of finish can be made through foam finishing technology. Advantages with the foaming process is that it contains foaming agents that are more concentrated. This results in increased dispersion by 5-20 fold. This foaming is applied on the fabric that passes through squeeze rolls and distributes the solution on the fabric (Fashinza, n.d.). After that, the fabric is put into a drying oven, but it only contains 15-35% of the water volume within the wet process (Aio.senars.com, 2021). From the financial perspective, Foam dyeing is a good choice since it does not require large investments (Abate and Tadesse, 2021).

According to Abate and Tadasse (2021), an advantage with Foam dyeing is the reduction in energy since low wet pickup is used. Another advantage is the reduced amount of water needed and as a result of that also the wastewater discharge is reduced. Further on, their study presents that Foam dyeing compared to pad dyeing leads to savings of water, energy and chemicals (Abate and Tadasse, 2021). But the method also has some disadvantages and one of them is that the foam stabilizers result in declining the dye molecule diffusivity which leads to increased risk of uneven dyeing. This method also requires a high equipment cost and has a limited range of aplicatable products (Textileapex.blogspot.com, 2015).

Comparison between Foam dyeing and Pad dyeing

Mohsin and Sardar (2019) compared the two methods called Foam dyeing and Pad dyeing. They used the same dye and recipe for both methods, with the exception of Pad dyeing not using a foaming agent. The lower pick up in Foam dyeing in combination with the higher blow ratio resulted in increased quantity of dye was required to get similar color depth as with pad dyeing. The study showed that increasing the dye percentage for the Foam dyeing from 1% which is the amount used in Pad dyeing, to 2,6%, resulted in similar or even better shade depth. Further, Moshin and Sardar (2019) present formulas for the textile industry to improve different decisions within the production regarding water, energy and chemicals. The study showed that using the same amount of dye in the two methods resulted in Foam dyeing exhibit lighter shade depth compared to the pad dyeing. But using 2,6% dye instead, Foam dyeing resulted in more dye concentration than Pad dyeing. Moshing and Sardar also concluded that Foam dyeing is a better method from an environmental sustainability point of view with both energy and water savings (Mohsin and Sardar, 2019).

An overview of the Foam dyeing method's water, energy and chemical use

Method	Water	Energy	Chemical
Foam dyeing method	Uses 5 times less water than in conventional dyeing methods. *(Yu, Wang, Zhong and Mao, 2014)*	Uses 23,54 kWh electricity for 1 ton of fabric compared to conventional dyeing methods that uses 122,29 kWh. (*Yu, Wang, Zhong and Mao, 2014)*	Minimizes Compared to conventional dyeing, the use of chemicals is much lower in Foam dyeing. (*Yu, Wang, Zhong and Mao, 2014)*

Table 13: An overview of the Foam dyeing methods water, energy and chemical usage

3.6.2 Airflow dyeing method

According to Abate and Tadesse (2021), Airflow dyeing is a method that reduces both water, energy and chemicals. In Airflow dyeing, textiles are dyed in a rope form in a closed tubular system. Airflow dyeing is an alternative method to conventional methods using a machine called jet dyeing machine (Abate and Tadesse, 2021). In the conventional method, the dyeing machine contains liquor where the fabric is moving in a padder which results in faster and more precise coloration (textilelearner.net, f, 2012). In Airflow dyeing, the textile is circulated by air instead of water which makes it faster and also reduces the water used (Abate and Tadesse, 2021).

The Airflow dyeing process starts with the textile being loosely loaded in the form of a rope and tied into a loop to minimize the tension and create a formation. Then the dyestuff and chemicals are injected into the circulation of air steam. A combination of the air steam and dye either sprayed or dispersed into the fabric. The method results in a good dyeing finish (Abate and Tadesse, 2021).

The Airflow machines are categorized under the batch type dyeing machines which means that both the bath and the material circulated while the fabric is being dyed. These types of dyeing machines do not have a large amount of water and chemical waste which makes it more environmentally sustainable. One of the latest upgrades of the Airflow machines is called “THEN Airflow Synergy” (Abate and Tadesse, 2021). Manufacturers claim that it is one of the machines with lowest liquor ratios. The Airflow dyeing method uses the aerodynamic principle which means that the fabric passes through a high-pressure air steam from a blower. The dye and chemicals are then atomized through a specific nozzle. Thereafter, the dye and chemicals are injected in a specific nozzle and sprayed in a managed quantity on the fabric. During the spraying, the liquor has large contact with the fibers and the fabric, creating an acceleration of the diffusion rate of the color. The machines used for Airflow dyeing are seen as batch type dyeing machines where both the fabric and bath of liquor are circulating. These machines use the lowest liquor ratio which results in less water and chemicals used. They are also faster and use less energy compared to similar machines used in some conventional methods (Abate & Tadesse, 2021).

The advantages using Airflow machines is that they require less water because the fabric is transported by air and steam which reduces the liquid ratio. The reduction of liquid ratio results in faster heating or cooling using less energy and also less salt and chemicals needed. Also the dye stuff can be reduced since most reactive dyestuffs can be improved in combination with lower liquor ratio. Reduced amount of dyestuff and the decreased time required results in cost reductions. Another advantage is that rinsing is made continuously where rinsing water is discharged without contact with the fabric. Because of that, in combination with the lower liquor ratios, Airflow dyeing uses 50% less water and heating energy compared to conventional methods. It also reduces the chemicals used with 40%, the salt used with 35% and the dyestuffs used with up to 10%. The Airflow dyeing also reduces the time for production processes by around 25% (Abate & Tadesse, 2021). As with many of the alternative methods, a disadvantage with the Airflow method is that the dyeing can be uneven on the fabric, because the dye is sprayed on the fabric (Lam, Xiaohui and Longhan, 2004).

An overview of the Airflow dyeing method’s water, energy and chemical use

Method	Water	Energy	Chemical
Airflow dyeing method	Uses 50% less water than the conventional methods but not as little as spray dyeing. *(Lam, Xiaohui and Longhan, 2004)*	The air-flow dyeing machines use 50 percent less energy than the conventional counterpart. *(Lam, Xiaohui and Longhan, 2004)*	Reduces chemicals with 40 percent, the salt with 35 percent and the dyestuff with up to 10 percent compared to the conventional methods. *(Lam, Xiaohui and Longhan, 2004)*

Table 14: An overview of the Airflow dyeing methods water, energy and chemical usage

3.6.3 Supercritical carbon dioxide dyeing method (ScCO2)

Another method that Abate and Tadesse (2021) mentions is the Supercritical carbon dioxide dyeing method. The method is using carbon dioxide which eliminates the water usage. The dyeing process involves loading the substrate to be dyed, CO2 compression, dyeing, rinsing, depressurization and lastly unloading. By using the ScCO2 method, 95 percent of the CO2 and 40 percent of the dyestuff can be recycled and reused (Abate and Tadesse, 2021).

When comparing the ScCO2 method with conventional dyeing methods, the ScCO2 method has more advantages. The ScCO2 method avoids using fresh-water and is therefore avoiding water pollution which is common in many other dyeing methods. No auxiliary chemicals are added during the dyeing process, instead disappearing agents or surfactants are used directly on the fabric. At the end of the dyeing process no substrate dyeing is needed because the fabric is completely dried after the expansion, which saves energy. The ScCO2 method results in both water, energy and chemical savings, meaning that this method has a better impact on the environment than many other dyeing methods. Abate and Tadesse are also pointing out that the method is saving costs up to 40-60 percent compared with a conventional dyeing method (Abate and Tadesse, 2021). But the method also has some disadvantages like a lack of data and knowledge about the dyestuff solubility in ScCO2 and the high pressure requirement for dye solubility (Agrawal, 2015).

An overview of the ScCO2 dyeing method's water, energy and chemical use

Method	Water	Energy	Chemical
ScCO2 dyeing method	Does not use any water. *(Abate and Tadesse, 2021)*	Reduces energy since the fabric already is completely dried after the expansion, but not as much as other alternative methods. *(Agrawal, 2015)*	Recycles 95 percent of the CO2 and that 40 percent of the dyestuff. *(Abate and Tadesse, 2021)*

Table 15: An overview of the ScCO2 dyeing methods water, energy and chemical usage

3.6.4 Spray dyeing method

In a Spray dyeing method the color is sprayed on the fabric, which in many cases is seen as a better option for the environmental sustainability than conventional dyeing methods. The method has been developed to minimize both water and chemical waste and is a complement to conventional dyeing methods that are often used today (Lin, Zhu, Zhang, Hossain, Oli, Pervez and Naddeo, 2021). The implementation of the Spray dyeing method on the other hand is a large investment and takes up a large area which is a disadvantage with the method (Hawachdryer.com, 2020).

3.6.4.1 Imogo

Imogo is a Swedish company that focuses on an environmentally sustainable production process within the textile industry. They have developed a machine called Dye-Max that performs a Spray dyeing technology that is reducing water, energy and chemicals by 90 percent compared with a conventional dyeing machine. The high water savings is possible due to the low liquid ratio, which is 0.5 liter per kilo fabric. The water waste savings is due to all dyes requiring dispersion being used and only 20 liters being used for changeovers. The reason behind the high energy savings is because of the low liquid content in the fabric, which is minimizing the required energy for heating and shortening the time needed for the fixation. The chemical savings is because of the low liquid ratio but also the spray process that is requiring less chemicals. The spray dye technology also results in a reduced amount of dye needed, but not a reduction in size with the reduction of water, energy and chemicals.

The dye savings is up to 30 percent, which is a result of the precise application and efficient fixation of the dye (Imogotech.com, n.d.)

3.6.4.2 Combination of wet fixation and dryeing treatment

A new and more sustainable variant of Spray dyeing method for cotton when using reactive dyes has been developed. According to Lin, Zhu, Zhang, Hossain, Oli, Pervez and Naddeo (2021), this method will save both water and energy. The conventional reactive dyeing system uses a water bath which consumes a lot of water, resulting in chemicals being thrown directly into watercourses before any treatment. The substances that are primarily thrown into the watercourses are auxiliaries, heavy metals and hydrolyzed reactive dyes, which all have a bad impact on the environment. To improve the environmental impact, new developments like Spray dyeing have been discovered.

The Spray dyeing method is used in jet-type overflow dyeing machines. Lin et al. (2021) mean that they have come up with an innovative continuous dyeing system, which includes preparation of the dye, spray dye on the fabric, dye fixation treatment, soapy washing of the unfixed dye and lastly drying the fabric. The advantages with this method is that there is no salt required and also retains the fabrics structure. When comparing the Spray dyeing method with Pad-dry-pad-steam, the Spray dyeing method has a combination of wet fixation and drying treatment for a high fixation rate but in a short time. The shorter wet fixation treatment and dyeing time results in both water and energy savings compared with the pad-steam-dry system (Lin et al., 2021).

An overview of the Spray dyeing method's water, energy and chemical use

Method	Water	Energy	Chemical
Spray dyeing method	The method is reducing the water usage with 90 percent which is a bit more than in the air-flow method. *(Imogotech.com, n.d.)*	Reducing the energy by 90 percent compared with the conventional methods. *(Imogotech.com, n.d.)*	Reducing chemicals by 90 percent compared with the conventional methods. *(Imogotech.com, n.d.)*

Table 16: An overview of the Spray dyeing methods water, energy and chemical usage

3.7 A summary of the alternative methods impact on environmental sustainability

The alternative methods' impact on environmental sustainability

Method	Positive impact on environmental sustainability	Negative impact on environmental sustainability
Foam Dyeing method	Reduces the use of water since the water is replaced by air. Reduces energy due to low wet pickup. Lower chemical usage than conventional methods.	Risk of uneven color finish.
Airflow Dyeing method	The textile is circulated by air instead of water which reduces the water usage. Uses 50% less water and energy compared to conventional dyeing machines. Reducing the chemicals used with 40%, the salt used with 35% and the dyestuffs used with up to 10% compared to conventional methods.	Risk of uneven color finish.
Supercritical carbon dioxide dyeing (ScCO2) dyeing method	The method is using carbon dioxide and does not use any water. 95 percent of the CO2 and 40 percent of the dyestuff can be recycled with ScCO2. No auxiliary chemicals are added during the dyeing process. No substrate drying is needed because the fabric is completely dried after the expansion, which saves energy.	Lack of data and knowledge about the dyestuff solubility in ScCO2 High pressure requirement for dye solubility
Spray dyeing method	The Dye-Max machine reduces wastewater, energy and chemicals by 90 percent compared with a conventional dyeing machine. No salt required and also retains the fabrics structure. The shorter wet fixation treatment and dyeing time results in both water and energy savings compared with the Pad-steam-dry method.	

Table 17: The alternative methods' impact on environmental sustainability

3.8 Alternative colorants for environmentally sustainable coloration

An alternative colorant is a new or improved colorant that can replace the conventional ones. The colorants presented in this chapter are chosen since they indicate to be more environmentally sustainable which is desired.

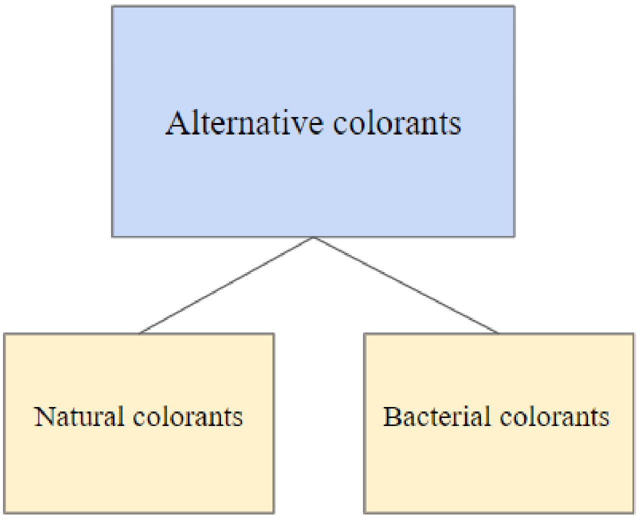

Figure 8: Alternative colorants

3.8.1 Natural colorants

Looking back in the history of textiles, it was initially colored with natural colorants, but the coloration process was later on replaced with chemicals. With the knowledge of the bad impact chemicals have on the environment, researchers like Baig et al. (2021) have considered bringing back the natural coloration. Natural colorants are based on raw material from nature such as vegetables, insects and plants. One example of a natural colorant that Baig et al. (2021) mentions is Marigold colorant, which comes from a yellow flower named Marigold. The Marigold colorant can produce different shades of yellow on cotton. According to Baig et al. (2021), the marigold natural colorant can be applied on the cotton fabric with two different methods, conventional and ultrasound assisted coloration. It was later on discovered that the ultrasound assisted coloration method was the better one since it saved around 16 percent of dye liquor, 14 percent less use of sodium chloride, less energy due to lower dyeing temperatures and less water waste if compared with the conventional dyeing method. The natural colorant can be an alternative to a more environmentally sustainable alternative of coloration. The marigold flower is one of many alternatives of a natural colorant (Baig et al. 2021).

The clothing company Patagonia is continuously working on decreasing their products' environmentally sustainable impact. In 2017, they presented a collection with natural colorants, called “The clean color collection”. The line contained products with both natural and biosynthetic colorants. The clothes with rosy colors came from the cochineal beetles which contain red carminic acid to fend off predators. To create green and beige color, herbal product waste was used. Patagonia found challenges with the usage of natural colorants and its color fastness. The natural colorants also resulted in undesired fading and one of the colors innovated were removed from the line because of this issue (Patagonia.com, 2017).

The poor color fastness and fading shades that Patagonia discovered is one of the main issues using natural colorants. It is also less reliable in the perspective that the colorant is based on raw material from nature and might therefore only be available during specific seasons and also in specific places. A large space of land is also required to be able to produce the raw material used for natural colorants. Since it is raw material from nature it is also difficult to get the exact same finish and color each time you use the same type of natural material to color the fabric (Biofriendlyplanet.com, 2019).

3.8.1.1 Archroma’s earth colorants

Archroma is a global leader of providing chemicals for among others, the textile industry. They have knowledge of chemistry since more than 130 years back and work actively with making the world more environmentally sustainable (Archroma.com, n.d. a). In 2021, they launched a coloration method called “LOVE NATURE X EARTH COLORS” which was explained as a coloration system using upcycled plant waste. The colorant is called “Diresul” and contains different natural waste from e.g almond and beetroot. The colorant is patented by Archroma and has optimum fastness in combination with possibility of build-up for more deep shades. Archroma also presents a coloration stability agent called “Reducing agent DST” with high effectiveness under alkaline conditions. It also has low sensitivity to atmospheric oxygen and the wastewater is salt-free. At last, they present their finishing process called “Direfix” which improves lightfastness and creates a soft handle. Archroma presents the benefits with their earthcolors in comparison to Pad-dry-pad-steam method using reactive dyes, which resulted in 23% less water consumption, 54% less energy consumption and 50% less chemical usage (Archroma.com, n.d. b).

3.8.2 Bacterial colorants

Another coloration method that is worth considering is coloring fabric with bacteria, which is environmentally sustainable because it does not require harmful chemicals. The bacterial coloration method is based on living organisms and does not require as much resources as other coloration methods. Bacteria do not need large spaces of land or large water resources which is an advantage. The method also results in a good result of color that is remaining on the fabric when compared with other natural coloration. With that said, the color finish is not as good as with conventional dyes e.g reactive dyeing (Ars.electronica.art, 2022). This is also a type of coloration that compared to other natural colorations from e.g flowers were not used back in the days, which means that it has not been tested as much and also not developed as much as it could be. It is also cheaper than other natural colorations since it does not require any chemicals, accepts lower temperatures and minimizes energy usage. Another advantage is that it can be produced everywhere and at any time in laboratories (Medium.com, 2021). On the other hand, the two designers Luchtman and Siebenhaar discuss the disadvantages with coloring fabric with bacteria. They are both educated within the fashion and textile industry with specialization within sustainability and started the company “Livingcolors” where they are coloring textiles with bacterial colorants through collaborations with scientists. They point out the fading colors as the biggest issue. As with all other natural coloration methods, a large problem area is the color fastness and the ability to make the textile retain the same shade even after washing it in the washing machine a few times or when it has been exposed to sunlight etc (Livingcolours.eu, 2020).

One company that has started using bacteria to color fabric is Colorifix, which developed a device that tested the water pollution in Nepal. They found out by using genetically modified bacteria the color changed when it was exposed to the toxic chemicals. This method resulted in a color changing reaction that developed a more environmentally sustainable colorant innovation that produces the color just as it is produced in nature. The process works by inserting the genetic information that is directing the color making process into a bacterial cell, the bacterial cell is then copying itself every 25 minutes. The bacterial cell is placed in a fermenting machine where the bacterial cell can rapidly multiply and by that produce more pigment. This alternative coloration method is both eco-friendly and cost competitive compared to conventional methods. The Colorifix technology reduces the water consumption with 49 percent, electricity with 35 percent and the CO2 emission with 31 percent compared to conventional methods. They are not using any heavy metals and organic solvents either which makes this new technology more environmentally sustainable. Among others, companies like Acatel and Forster Rohner are today using Colorfix bacterial method to color their fabrics in a more environmentally sustainable way and also H&M is planning to launch a collection using their bacterial colorant. Today, Colorfix has more customers than they can provide colors for and themselves are sure that this is just the beginning of the bacterial colorant usage (Colorifix.com, 2022). According to Lellis, Fávaro-Polonio, Pamphile and Polonio (2019), issues regarding the absorption capacity in the final disposal of the biomass and the pretreatment occur when using bacterial colorant, which is one of the disadvantages with the method.

3.9 A summary of the alternative colorants impact on environmental sustainability

The alternative colorants' impact on environmental sustainability

Colorant	Positive impact on environmental sustainability	Negative impact on environmental sustainability
Natural colorants	Do not cause pollution Renewable Raw material from nature Reduces the water consumption with 23%, electricity with 54% and chemicals with 50% compared to conventional colorants.	Worse colorfastness compared to both conventional colorants and bacterial colorants. Require a lot of land space when produced
Bacterial coloration	Does not require harmful chemicals Bacteria do not need large spaces of land Reduces the water consumption with 49 percent, electricity with 35 percent and the CO2 emission with 31 percent compared to conventional colorants.	Issue with the absorption capacity in the final disposal of the biomass Worse colorfastness than conventional colorants

Table 18: The alternative colorants' impact on environmental sustainability

4. Empirical data

The chapter initially presents the supplier of the product Dvala, the first supplier. After that, the first supplier's wet dyeing process is introduced. Then their two used methods are described, the Cold pad batch and Pigment dyeing, including the water, energy and chemicals used. The chapter continues with a presentation of the second supplier. Followed by a description of their wet dyeing process when producing the towel Vågsjön. After that, a detailed description of their used method, Pad-dry-pad-steam, including the water, energy and chemicals used are presented.

4.1 About the first supplier

The supplier that IKEA uses to produce “Dvala" is located in Pakistan and is the largest exporter of textile in Pakistan and has over 9 000 employees. They have a long relationship of 28 years with IKEA which also makes them a prioritized supplier. IKEA stands for 30 percent share of their production. They are shipping between 90-100 containers to IKEA per month and produce 18 million pieces to IKEA per year (Production engineer at supplier one, 220216). According to their Manager with specialization within product development (220216), IKEA is keen to improve the environmental sustainability and through the years, a lot of the improvements made in the production were developed together with them. They have in the last few years noticed an increased interest among their other customers as well, regarding creating a more environmentally sustainable production of their products (Manager with specialization product development at supplier one, 220216).

The raw material and cotton are purchased by the first supplier from sub-suppliers. They communicate that suppliers that produce chemicals are very limited. The sub-suppliers can either be nominated by IKEA or chosen by the first tier supplier. The first supplier is responsible to find 95 percent of the sub-suppliers by themselves and IKEA is responsible to nominate 5 percent of the sub-suppliers. For the first supplier to be able to guarantee IKEA that also their sub-suppliers are following the guidelines within the IWAY, unarranged audits are made regularly (Production engineer at supplier one, 220216).

4.2 The first suppliers wet dyeing process when producing Dvala

The first supplier that produces Dvala, is using two different conventional methods and two different colorants which results in two different wet dyeing processes. The first method is Cold pad batch which includes reactive dyes and are used when producing darker and deeper colors, e.g black and dark blue. The second method used is Pigment dyeing which is used for the lighter shades within the Dvala collection, e.g light yellow and white. The reason for using a different method when producing bedsheets in lighter colors depends on the non requirement of washing off chemicals which reduces both water and chemical use. It is also less complicated and relatively cheap. Therefore, as much as possible is produced with the Pigment dyeing method while the products that require a dark and deep coloration need to be produced with the Cold pad batch method to reach desirable results. The first supplier has been using the same methods for 10 years which they explain depends on the huge investments that a change of methods or machines almost always result in (Production Engineer at supplier one, 220216).

4.3 The first suppliers wet dyeing process using the Cold pad batch dyeing method

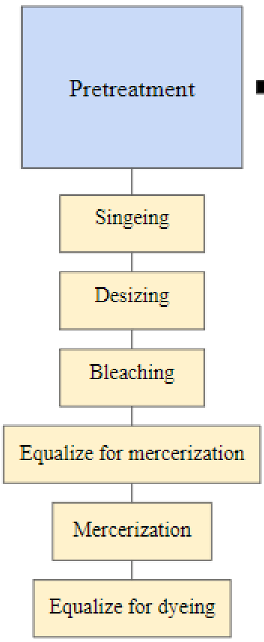

Figure 9: The first suppliers wet dyeing process using the Cold pad batch dyeing method

The wet dyeing process starts with singeing, desizing and bleaching, which all are a part of the pretreatment. The former means that the fiber ends protruding are being scorched and gassed to get a smooth fabric when a fluffy material is not required. The desizing process includes usage of desizing agents which are bacterial amylases and subsequent steaming, whereby the starch is decomposed at an accelerated rate. These two processes are made in the same machine which is called the Singe-desize-machine. The next step in the pretreatment is bleaching, which is made to remove the tints contained in the gray fibers to prepare for the dyeing and finishing process. This process turns the fabric from a desized fabric to a bleached fabric through bleaching. The sixth step in the Cold pad batch method is the equalization for mercerize which is the pre step before the mercerization, where the fabric gets equalized and dimensional stability through dry heat. After that, the fabric is ready for the mercerization. The mercerization is a pretreatment of cellulosic textiles with a concentrated solution of caustic soda where the fibers are swollen and the strength and dye affinity of the material are increased. When the mercerization is done, the next step is equalize for dyeing which is the same process as before the mercerization, a process of conferring dimensional stability on the fabric through dry heat (Production engineer at supplier one, 220216).

After that, the fabric is ready for coloration. The colorant is applied through the padder, a fabric opening and rolling machine that guarantees a crease-free material. After the padding and cold dwelling, the fabric must be washed in a suitable way. Therefore, the next step is the washing process where the unfixed dyes and chemicals are washed off in several sections. 50-60% of the water used for washing is reused and directed in counter-flow where fresh water is supplied at the point where the textiles leave the machine. The next step is finishing where improvements of the fabric's performance and appearance are done. The last step is the sanforizing which includes mechanical compacting and is a method for reducing residual shrinkage. The process forces yarns closer together for the fabric to become thicker and heavier (Production engineer at supplier one, 220216).

4.4 Water, energy and chemicals used with the Cold pad batch dyeing method

The singeing and desizing within the pretreatment process is presented as grams per liter since the fabric passes through the desizing machine, which contains desizing liquor. The first supplier is therefore measuring each chemical in grams per one liter of water which is the liquid that goes into the desizing machine. The bleaching process within the pretreatment is presented as milliliters per kilogram which presents how many milliliters of each chemical that is used for one kilogram of fabric. In this part the fabric is weighted and the first supplier is aware of how many milliliters of each chemical that is required for bleaching one kilogram of fabric (Production engineer at supplier one, 220518). The mercerization within the pretreatment process is measured in *be which stands for Baumé degrees that measure relative density of liquids by hydrometry. It is a measurement that shows how thick the liquid is. This is important in order to know how much caustic, strong or weak, that is flowing into the machine (Material and Technology Engineer at IKEA, 220518).

Measuring chemicals used for coloration follows the same procedure as for singeing and desizing which means that each chemical and colorant is measured in grams per liter water. The coloration process contains reactive dyes and chemicals that are being padded onto the fabric and then stored in batches where it is rotating. The first supplier measures the amount of dyes and chemicals in grams per liter of water instead of milliliters per kilogram of fabric. Their production engineer communicates that it is easier to receive that information compared to calculating how much of each chemical that is applied on each kilogram of fabric (Production engineer at supplier one, 220518).

In the finishing process for the method Cold Pad batch, a machine is used for stretching the fabric. This process also requires finishing chemicals that are applied by a machine. These chemicals are measured in grams per liter of liquid that goes into the machine used for finishing (Production engineer at the first supplier, 220518).

Cold pad batch dyeing method

Chemicals used for pretreatment (Singeing and Desizing)	Amount of chemical used
Oxalic Acid	5 g/l
Setawash RG	3 g/l
Beixon Q	1 g/l
Aquazym AD	1,5 g/l
Chemicals used for pretreatment (Bleaching)	**Amount of chemical used**
Caustic Soda	25 ml/kg
Setawash RG	4 ml/kg
Setacrystal RNE	2 ml/kg
Contavan DSP	7 ml/kg
Hydrogen perdoxide 50 %	35 ml/kg
Chemicals used for pretreatment (Mercerization)	**Amount of chemical used**
Caustic soda, strong Lye	27-30 *be
Caustic soda, weak Lye	06-08*be
Chemicals used for coloration	**Amount of chemical used**
Bezakiv Yellow HP-NP	18.7 g/l
Proder M AC Nuevo	0.5 g/l
Urea	25 g/l
Soda Ash	30 g/l
Caustic Soda	7 g/l
Chemicals used for finishing	**Amount of chemical used**
Setafen PS	5 g/l
Appretan EMJP	5 g/l
Flofix 56 DAC	10 g/l
Jintex ECO WRN	30 g/l
Acetex Plus	3 g/l

Water	Amount of water used
Per kg fabric	55,41 l
Energy	**Amount of energy used per kg fabric**
Electricity	0,15 kWh
Steam	2,2 kg

Table 19: Cold pad batch method

4.5 Supplier one's wet dyeing process using the Pigment dyeing method

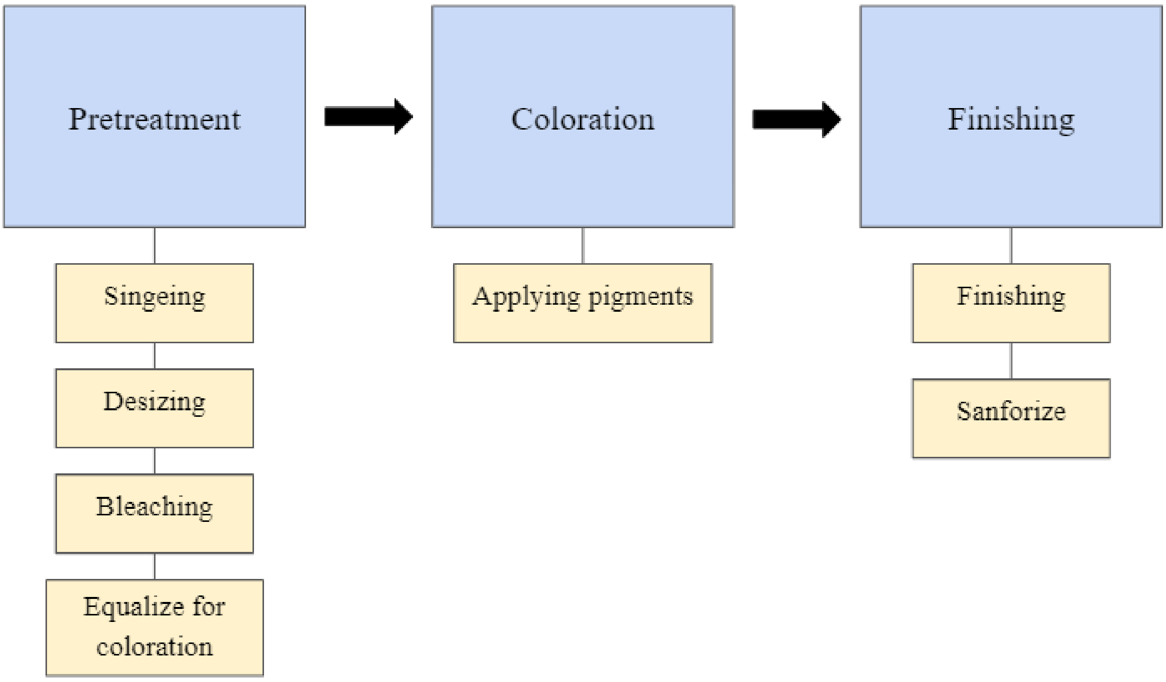

Figure 10: Supplier one's wet dyeing process using Pigment dyeing method

The Pigment dyeing method follows the exact same steps as the Cold Pad Batch method, except three steps. The processes that differ from the Cold pad batch are the equalizer for mercerize, mercerization and the second washing. These steps are the ones including and handling the chemicals. Pigment dyeing is a method where pigments are applied on the surface of the fabric. The pigments are water insoluble and the method does not contain chemicals that need to be washed off. Instead, the fabric goes into a batch containing a binder for color fixation. The last step is the finishing which includes sanforization. The sanforize reduces the shrinkage by compacting the fabric. When the finishing step is accomplished, the fabric performs, feels and looks in a desirable way and the wet dyeing process is done (Production engineer at supplier one, 220216).

Pigment dyeing is more environmentally sustainable than other methods that supplier one is using since it does not require as many chemicals and also less water. However, it is not as used as the conventional methods using reactive dyes since it is not as durable (Production engineer at supplier one, 220216).

4.6 Water, energy and chemicals used with the Pigment dyeing method

In the Pigment dyeing method, the first processes within the pretreatment are presented in grams per liter due to the fabric being passed through the desizing machine, which contains desizing liquor. Each chemical used in this process is therefore presented in grams per liter of liquor. The bleaching section within the pretreatment is on the other hand presented as milliliters per kilogram. This means that each chemical is presented in how much in milliliters that are required for one kilogram of fabric (Production engineer at supplier one, 220518).

The coloration process is measured in grams per liter of water and the reason for that is that the fabric goes into a batch containing pigments and a binder for color fixation. Supplier one does not measure the pigments or chemicals within the coloration process for each kilogram of fabric. Instead, they measure how much of each chemical and pigment that one liter of water contains (Production engineer at supplier one, 220518).

Lastly, the finishing process is measured in grams per chemical used for each liter of water. This depends on the machine used for finishing where the liquid is carried through a specific liquid supply and then applied on the fabric through rotors creating a fine application of droplets (Production engineer at supplier one, 220518).

Pigment dyeing method

Chemicals used for pretreatment (singe desize)	Amount of chemical used
Oxalic Acid	4 g/l
Lavotan RGA	4 g/l
Bexion Q	2 g/l
Aquazym AD	0.5 g/l
Chemicals used for pretreatment (Bleaching)	**Amount of chemical used**
Caustic soda	25 ml/kg
Lavotan RGA	4 ml/kg
Heptol BNF	2 ml/kg
Contavon DSP	6 ml/kg
Hydrogen Peroxide	28 ml/kg
Chemicals used for coloration	**Amount of chemical used**
Imperon Yellow HF-R	0.126 g/l
Qasmobinder 9915 dyeing	30 g/l
Qasmobinder P c. SOFT	20 g/l
Solidokoll V Liq	18 g/l
Profix ICY 50	10 g/l
Kolasol CDA	1 g/l
Padicoll DYE	5 g/l
Chemicals used for finishing	**Amount of chemical used**
Rucofin GWA	25 g/l
Water	**Amount of water used**
Per kg fabric	17, 64 l
Energy	**Amount of energy used**
Electricity per kg fabric	12,69 Kwh
Steam per kg fabric	9 kg

Table 20: Pigment dyeing method

4.7 About the second supplier

The second supplier is producing the product “Vågsjön" and is based in India. They have two different locations in India, the head office which is located in Ludhiana Punjab and the factory that is located in Dhualla punjab. In the factory, 2368 employees are working. About 20 percent of their production capacity is used for IKEA’s products (Sales Team Leader at supplier two, 220517). As supplier one communicated (Production Engineer at supplier one, 220216), also supplier two has noticed an increased interest from customers to change the production of their products into a more environmentally sustainable process. They also agree with supplier one regarding the fact that IKEA since years back actively are trying to improve the production process into becoming more environmentally sustainable. Despite this, they find it hard to make the changes become reality since it requires a lot of financial resources and calculations to make sure that potential investments or changes to alternative methods or colorants would actually lead to an improvement (Sales Team Leader at supplier two, 220518).

Supplier two is purchasing material like the colorants, chemicals and packaging materials from sub-suppliers when producing the product “Vågsjön”. To control that the sub-suppliers are following the rules and code of conduct that IKEA has, the IWAY, Supplier two arrange unplanned audits. By doing unarranged audits at the sub-suppliers, they can guarantee IKEA that the rules are followed correctly (Sales Team Leader at supplier two, 220518).

4.8 Supplier two’s wet dyeing process when producing Vågsjön

When producing the product “Vågsjön”, supplier two is using the method Pad-dry-pad-steam. All the different colors in the range are produced with the Pad-dry-pad-steam method. The method is using a high consumption of energy because of the intermediate drying and it also results in high chemical waste. Supplier two claims that they are using the Pad-dry-pad-steam method since it is effective and also results in excellent color finish (Sales Team Leader at supplier two, 220518).

Supplier two are continuously looking over their current processes to possibly make improvements within e.g the wet dyeing process. Despite this, it was a long time ago they changed a method or process. An implementation made to become more environmentally sustainable is that they are treating their water waste using their own ETP plant which means that they are treating the industrial waste water so it can be reused. They are using the treated waste water in their premises for plantation purposes (Sales Team Leader at supplier two, 220518).

4.9 The wet dyeing process using the Pad-Dry-Pad-Steam dyeing method

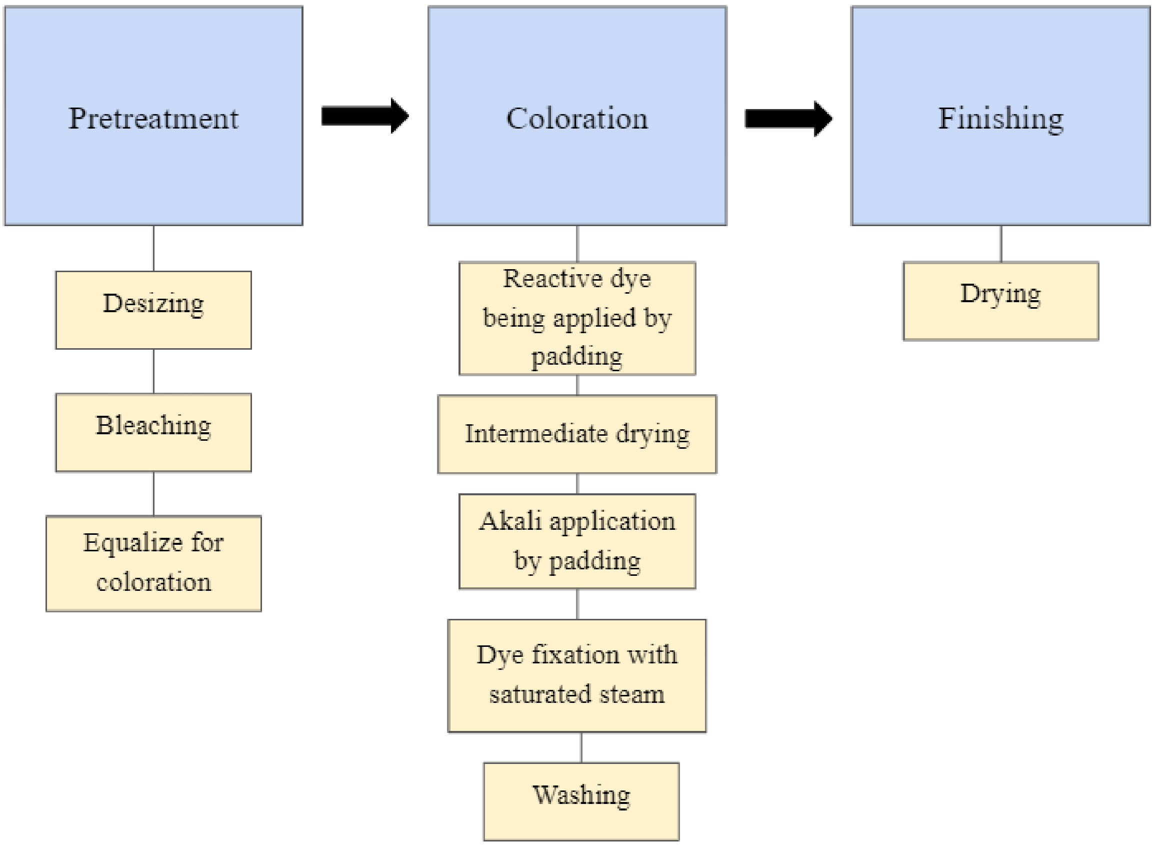

Figure 11: Supplier two's wet dyeing process using Pad-dry-pad-steam dyeing method

The wet dyeing process within the Pad-dry-pad-steam method starts with pretreatment. The pretreatment is made to make the fabric prepared for the upcoming coloration to get the best fabric finish possible. Before the pretreatment, the fabric is filled with a starch-based sizing agent. Because of this, the first step in the pretreatment is an application of enzymes to be able to remove the sizing agent. Supplier two is combining both desizing and bleaching through immersing the fabric in a bath that contains chemicals, more specific peroxide, caustic soda, contavan and green acid. In this bath, a wetting agent is also included to improve the penetration and spreading of the chemicals since it reduces the surface tension of the fabric. After that, a process of conferring dimensional stability on the fabric through dry heat is made, called equalize for coloration.

The coloration process begins with the dye being applied through padders that squeezes the dyes into the fabric with pressure. After that, the fabric is being dried. When the fabric is intermediate dried, the chemicals are then padded onto it. The fabric is then exposed to dye fixation with saturated steam and lastly, the fabric is washed off to eliminate dyestuff and chemicals used (Sales Team Leader at supplier two, 220518).

When the fabric is washed off from both chemicals and dyestuff, it is time for the next and last step in the wet dyeing process, which is the finishing. In this step the fabric will be completely dried and treated with chemicals required to get the desired surface of the fabric which is soft and smooth (Sales Team Leader at supplier two, 220518).

The Pad-dry-pad-steam method’s wet dyeing process is not performing the best from an environmentally sustainable aspect. The method’s wet dyeing process has a large energy waste because of intermediate drying and many chemicals are used during the coloration process (Sales Team Leader at supplier two, 220518).

4.10 Water, energy and chemicals used in the Pad-dry-pad-steam dyeing method

Supplier two measures all the sections within the pretreatment in milliliters of each chemical needed per kilogram of fabric which means that they are aware of how much of each chemical in milliliters that is needed for one kilogram of fabric (Sales Team Leader at supplier two, 220518).

The coloration process is measured in grams per liter of water since the fabric is passed through pad rollers that are squeezing the dye into the fabric. Supplier two is only measuring the liquid going into the padding machine and not for each kilogram of fabric. The chemicals and dye used for coloration are therefore measured in grams per liter of water which is the liquid that later on is inserted in the machine for squeezing into the fabric through padders

(Sales Team Leader at supplier two, 220518).

In the finishing process, the chemicals needed are directly padded onto the fabric before going into the stenter machine. The process also contains water that together with the chemicals are added continuously to the padding liquid, otherwise the liquid would eventually run out. To be able to guarantee that the concentration of the liquid is the same at all times, they are therefore measuring each chemical needed in grams per liter of liquid (Material and Technology Engineer at IKEA, 220518).

Pad-dry-pad-steam dyeing method

Chemicals used for pretreatment	**Amount of chemicals used**
Enzyme	1,4 ml/kg
Wetting agent	2,6 ml/kg
Caustic soda	21 ml/kg
Hydrogen Peroxide	20 ml/kg
Contavon BA	1,5 ml/kg
Green acid	4 ml/kg
Chemicals used for coloration	**Amount of chemicals used**
Defoamer	0,5 g/l
Resist salt	1,5 g/l
Acetic Acid	0,2 g/l
Salt	40 g/l
Soda ash	60 g/l
Chemicals used for finishing	**Amount of chemicals used**
Hydrophilic Softener	15 g/l
Invatex AC	0,325 g/l
Water	**Amount of water**
Per kg fabric	70 l/kg
Energy	**Amount of energy used**

Electricity per kg fabric	6 kWh
Steam per kg fabric	5 kg

Table 21: Pad-dry-pad-steam dyeing method

5. Analysis

The analysis begins to discuss IKEA's suppliers' current wet dyeing processes and how environmentally sustainable they are in terms of water, energy and chemicals. After that, the alternative dyeing methods and colorants are compared with each other in order to come to a conclusion about which alternative method and colorant that is the most beneficial to implement for improve environmental sustainability and reduce the water, energy and chemical use.

5.1 Research question 1: How environmentally sustainable are IKEA's suppliers' wet dyeing process in terms of water, energy and chemicals used?

To be able to analyze the suppliers usage of water, energy and chemicals and in that way also discuss their impact on environmental sustainability, the researchers are ranking the conventional methods in table 22, based on theoretical sources with the empirical data taken into consideration. Each method's usage of water, energy respectively chemicals are ranked from 1 to 3 where 1 is the most environmentally sustainable and 3 is the least environmentally sustainable.

How the different conventional methods' uses water, energy and chemicals

Method	Water	Energy	Chemicals
Pad-dry-pad-steam dyeing method	**3** A lot of water is needed in the washing process to wash off all chemicals. *(Yu, Xi, Lu, Tao and Yi, 2020)*	**2** A high consumption of energy due to the intermediate drying. *(Zhang, Fang, Zhang, Shu, Gong and Liu, 2017)*	**3** A lot of chemicals are used because of reactive dyes. *(Zhang, Fang, Zhang, Shu, Gong and Liu, 2017)*
Cold pad batch dyeing method	**2** Less water than Pad-dry-pad-steam because of reduced liquor ratio. *(Geberehiwot, KA, 2020)*	**1** Less energy use than Pad-dry-pad-steam because of a cold process. *(Geberehiwot, KA, 2020)*	**2** Lower chemical use than Pad-dry-pad-steam since they are not used to speed up the reaction. *(Geberehiwot, KA, 2020)*
Pigment dyeing method	**1** Lowest water consumption because no chemicals to wash off. *(Chakraborty, 2014)*	**3** Higher energy usage than methods using reactive dyes because of the curing process. *(Chakraborty, 2014)*	**1** Low chemical use because pigments are used for coloration. *(Chakraborty, 2014)*

Table 22: How the different conventional methods use water, energy and chemicals

The first supplier is using the Pigment dyeing method for lighter shades and the Cold pad batch method for darker shades when producing the product Dvala, which they motivate is the most environmentally sustainable choice that also results in desired color finish. That is confirmed by Geberehiwot and KA (2020) which present Cold pad batch as the most environmentally sustainable conventional dyeing method using reactive dyes, able to deliver all types of shades. Supplier one reasoning and choice of methods is also confirmed by Chakraborty (2014) who explains that the Pigment dyeing method is better from an environmentally sustainable perspective compared to all conventional methods using reactive dyes, including both the Cold pad batch method and the Pad-dry-pad-steam method. But the Pigment dyeing method has limitations and the reason why supplier one is using another method in combination with it, is because it can only produce lighter shades. That limitation forced supplier one to use another method in combination with the Pigment dyeing method, to be able to sell the product Dvala in all shades, including darker ones. To be able to do that and at the same time guarantee a desirable color finish, they chose the Cold pad batch method.

Supplier two on the other hand is only using one dyeing method for producing all shades of the product Vågsjön, the Pad-dry-pad-steam method that requires reactive dyes. They motivate their choice of method with that Pad-dry-pad-steam is both fast and results in excellent color fastness. As El-Molla et al. (2015) explains, reactive dyes result in increased water usage in combination with more chemicals being included in the wet dyeing process. According to Geberehiwot and KA's (2020), the Cold pad batch method is more environmentally sustainable compared to other methods using reactive dyes, including the Pad-dry-pad-steam method, which is supported by the data collected from IKEA's two suppliers. The collected data shows that water, energy and chemicals are reduced when using the Cold pad batch method instead of the Pad-dry-pad-steam method. When using the method Cold pad batch, supplier one presents that 55,41 liters of water is required for one kilogram of fabric compared to supplier two's method Pad-dry-pad-steam, which requires 70 liters of water for one kilogram of fabric. Also the use of energy is reduced when using the Cold pad batch method instead of the Pad-dry-pad-steam method since it is a cold process which requires less heating. Supplier one states that they are using 0,15 kWh electricity and 2,2 kilogram steam for each kilogram of fabric compared to supplier two that uses 6 KwH electricity and 5 kilogram steam within their Pad-dry-pad-steam method for the same amount of fabric. As Chakraborty (2014) presents, the most environmentally sustainable method among the conventional methods is the Pigment dyeing. In terms of energy usage, however, it is the worst performing conventional methods, which is seen in the ranking in table 22. It is also stated in the data collected from the first supplier which presents that 12,69 Kwh electricity and 9 kilogram of steam are required for one kilogram of fabric. In the other two categories, water and chemicals, the Pigment dyeing method is performing best among the conventional methods and are therefore having the best ranking in these columns in table 22. As seen in the data collected from supplier one, the wet dyeing process using the Pigment dyeing method only results in 17,65 liters of water required for each kilogram of fabric. That is a large reduction of water usage compared to the other two conventional methods.

According to Geberehiwot and KA (2020), the amount of chemicals needed in the Cold pad batch method are less than within other conventional dyeing methods that use reactive dyes, including Pad-dry-pad-steam, since the dye is optimally utilized. The Pad-dry-pad-steam method is also less environmentally sustainable than the Cold pad batch methods because of the salt required within the wet dyeing process (Zhang et al., 2017).
Pigment dyeing on the other hand is using the lowest amount of chemicals of the three conventional methods since it uses pigments instead of reactive dyes for coloration. Less chemicals are also being used due to the fact that no after treatment is needed in the process, instead there are binders used to reach the good colorfastness (Chakraborty, 2014).

The comparison between the three different conventional methods used by IKEA's suppliers shows that the Pigment dyeing method is the most environmentally sustainable in terms of chemicals and water while the Cold pad batch method is best in terms of energy usage. Overall, as seen from the ranking in table 22, the Pigment dyeing method is performing best, with the highest score in two of three categories. But since IKEA has a wide range of colors for both Dvala and Vågsjön and the Pigment dyeing method only can produce light shades, it results in a need for an additional method that can produce the darker shades. A combination of the Cold pad batch method and the Pigment dyeing method are therefore resulting in desired color fastness for all shades, with the best environmentally sustainable impact, when choosing among the conventional methods that IKEA's suppliers are using today. This results in IKEA's first supplier being more environmentally sustainable compared to the second supplier. But as The Economist (2021) presents, the world and the textile industry are constantly changing which means that all conventional methods need to be evaluated and developed. Even though supplier one is having a better wet dyeing process compared to supplier two, it does not mean that it is optimal. That supplier one and Supplier two have been using the same methods for about 10 years supports that reasoning, since a lot has happened on the textile market and within the wet dyeing process during those years. Even though the methods that they are currently using were the most environmentally sustainable 10 years back, does not mean that it is the case today. Another issue is the fact that the two suppliers used are IKEA's largest textile suppliers and are producing corresponding products with different methods that affect environmental sustainability differently. That shows that the wet dyeing process has not been taken care of by IKEA since an investigation of different methods within the process would make it possible to come to a conclusion on what method that IKEA wants all their suppliers to use to become as environmentally sustainable as possible. Letting each supplier choose their own methods results in, as shown in table 22, that each supplier affects the environment differently and IKEA loses the control of their environmental impact. To be able to improve the impact on environmental sustainability, IKEA should therefore search for alternative methods to reduce the usage of water, energy and chemicals within the wet dyeing process to be able to later on implement it on all their suppliers.

5.2 Research question 2: What improvements could be done in the wet dyeing process to improve environmental sustainability?

As Madhav et al. (2018) presented, improvements within the wet dyeing process and the textile production in general is important because of its huge impact on environmental sustainability. Having a company and not focusing on developing the process towards a more sustainable production are related to risks, e.g reduced profitability. Therefore, it is convenient for all businesses within the textile industry to investigate their textile productions and search for potential improvements for increased environmental sustainability. Improvements regarding colorants and methods as well as techniques are discussed for potential improvements towards a more environmentally sustainable textile industry.

According to Kerle et al. (2021), to be able to become more environmentally sustainable, it is advantageous to involve customers. The fact that different colors can be produced with different methods that affect environmental sustainability in different ways, makes it possible for companies to share this information. As Kerle et al. (2021) presents, it becomes more and more important for customers to be aware of the production of the products they buy, and also the transparency within the supply chain. Spreading the information about how different shades affect environmental sustainability in different ways could therefore increase companies' possibility to reduce their negative environmental impact. As Chakraborty (2014) presents, darker shades are the most harmful while lighter shades can be produced in more sustainable processes and methods. Marketing this would make society and the customers more aware of how their buying behavior affects the environmental sustainability and since there is an increased trend in reducing their environmental footprint, it will make these items more demanded. In that way, companies actively steer their customers to more environmentally sustainable options which also reflects on the company that can increase the amount of products they can produce with improved environmental sustainability. This would also lead to customers' trusting the company more as a result of the transparency and information sharing. In addition it will create a feeling among customers that they are making a conscious choice for environmental sustainability.

5.2.1 Water

Water waste is one of the large environmental issues that needs to be addressed in the textile industry. Madhav et al. (2018) points out that the wet dyeing process is one main contributing factor to the large water waste and that it takes about 50 to 100 liter water to produce 1 kilogram of textile. Therefore, if a company or supplier could choose a coloration method that uses less water than the ones they are using today, they should really consider it. One method that is only using a small amount of water in the wet dyeing process is the Foam dyeing method that replaces water with air in some of the stages of the process. According to Yu, Wang, Zhong and Mao (2014), Foam dyeing uses five times less water than conventional dyeing methods.

Companies that are using conventional methods today could also replace it with the Air-flow dyeing method to reduce their water usage (Abate and Tadesse, 2021). Abate and Tadesse (2021) points out that the Air-flow dyeing method is using less water by replacing some stages in the process with air. Another method worth considering is Spray dyeing which means that the dye is sprayed on the fabric and is according to Lin et al. (2021) resulting in decreased usage of water with 90% compared to conventional methods. When considering the water usage aspect, the Spray dyeing method is a better choice than the Air-flow dyeing method. Both methods are reducing the amount of water needed, but Spray dyeing is reducing the water usage with 90 percent which is more than in the Air-flow method, which reduces water by 50 percent compared with conventional methods.

Another environmentally sustainable dyeing method that can replace the conventional dyeing methods is according to Yu et al. (2014) the supercritical carbon dioxide dyeing method (ScCO2). The method does not use any water at all since it is replaced by carbon dioxide. This means that the best method from the perspective where reducing water is the most desirable, the ScCO2 is the one to prefer, due to no need of water in the method. The companies and suppliers using a conventional method today to dye their fabric should consider changing it to the ScCO2 method if they want to reduce the waste water in their current wet dyeing process.

5.2.2 Energy

In the wet dyeing process it is preferable to use as little energy as possible if the company wants to be more environmentally sustainable. Energy has a negative impact on the environment and a reduction of it in some or many sections within the wet dyeing process would result in a more environmentally sustainable process for the textile industry.

One alternative method that uses less energy in the wet dyeing process is Foam dyeing, which saves energy due to the water being replaced by air. The minimal water usage is also resulting in decreasing energy use. According to Yu, Wang, Zhong and Mao (2014) Foam dyeing is using 23,54 kWh electricity for 1 ton of fabric compared to conventional dyeing that uses 122,29 kWh for the same amount of fabric. Another alternative method to replace conventional dyeing for reduced energy usage is ScCO2. The method reduces energy since the fabric already is completely dried after the expansion. That results in an elimination of a whole production step that consumes energy in the conventional dyeing methods. The ScCO2 is therefore a more environmentally sustainable choice to reduce the energy within the production of textiles.

Similar to the reduction of water, Air-flow dyeing also results in lower energy usage compared to conventional methods because of its reduced energy usage during heating. Another method that is more environmentally sustainable regarding energy compared to conventional methods is the Spray dyeing method that includes the machine called "Dye-Max" which reduces the energy by 90 percent compared with conventional Pad methods. Spray dyeing also has a shorter wet fixation treatment and dyeing time which results in both water and energy savings compared with Pad methods. The reason behind the large energy savings is the low liquid content in the fabric, which is minimizing the required energy for heating and shortening the time needed for the fixation.

5.2.3 Chemicals

The chemical waste in the textile industry is a large problem, especially for methods using reactive dye. Many chemicals are being released in the wet dyeing process which affects the environment negatively. Among the alternative methods, Foam dyeing uses less chemicals compared to conventional dyeing methods. Yu, Wang, Zhong and Mao (2014) explains that the Foam dyeing method minimizes the chemical used compared to the conventional dyeing methods. The method allows a one sided treatment when dyeing the fabric which results in a lower chemical use. Another method that also is a better alternative than conventional method is the ScCO2 method due to the fact that no auxiliary chemicals are added during the dyeing process. Instead, disappearing agents or surfactants are used directly on the fabric. Abate and Tadesse (2021) also point out that the ScCO2 recycles 95 percent of the CO2 and that 40 percent of the dyestuff can be recycled.

The Airflow dyeing method is a better alternative when considering the handling and usage of chemicals compared to conventional methods. The Airflow dyeing method is using machines that are categorized under the batch type dyeing machines which means that both the bath and the material is dyed when it is being circulated. These types of dyeing machines do not waste a large amount of water and chemicals which makes it more environmentally sustainable. According to Abate and Tadesse (2021), the Airflow dyeing method reduces chemicals with 40 percent, the salt with 35 percent and the dyestuff with up to 10 percent compared to conventional methods.

5.2.4 Recommended alternative methods

How the different alternative methods' uses water, energy and chemicals

Method	Water	Energy	Chemical
Foam dyeing method	**4** Uses 5 times less water than in conventional dyeing when dyeing the same amount of fabric. (*Yu, Wang, Zhong and Mao, 2014)*	**2** Foam dyeing is using 23,54 kWh electricity for 1 ton of fabric compared to conventional dyeing that uses 122,29 kWh. (*Yu, Wang, Zhong and Mao, 2014)*	**4** Compared to conventional dyeing, the use of chemicals is much lower in Foam dyeing. (*Yu, Wang, Zhong and Mao, 2014)*
ScCO2 dyeing method	**1** Does not use any water. *(Abate and Tadesse, 2021)*	**4** Reduces energy less than other alternative methods but better than conventional methods since the fabric is completely dried after the expansion *(Agrawal, 2015).*	**3** Recycles 95 percent of the CO2 and that 40 percent of the dyestuff. *(Abate and Tadesse, 2021)*
Airflow dyeing method	**3** Uses 50% less water than the conventional methods but not as little as spray dyeing. *(Lam, Xiaohui and Longhan, 2004)*	**3** The air-flow dyeing machines use 50 percent less energy than the conventional ones. *(Lam, Xiaohui and Longhan, 2004)*	**2** Reduces chemicals with 40 percent, the salt with 35 percent and the dyestuff with up to 10 percent compared to conventional methods. *(Lam, Xiaohui and Longhan, 2004)*
Spray dyeing method	**2** Reducing the water usage with 90 percent which is a bit more than in the air-flow method. *(Imogotech.com, n.d.)*	**1** Reducing the energy by 90 percent compared with the conventional methods. *(Imogotech.com, n.d.)*	**1** Reducing chemicals by 90 percent compared to conventional methods *(Imogotech.com, n.d.)*

Table 23: How the different alternative methods are using water, energy and chemicals

As seen in table 23, the best method in terms of water, energy and chemicals is the Spray dyeing method. The researchers ranked the alternative methods from 1-4, where 1 is the best and 4 is the worst from an environmentally sustainable perspective. This ranking is based on how the methods perform in each specific field, e.g water usage. In that way, it is easier to see how the different methods perform compared to each other.

Every alternative method mentioned is reducing water, energy and chemicals compared to the conventional methods. Some of the methods are better than others when it comes to reducing the water, energy and chemicals as shown in table 23. Foam dyeing is one of the alternative methods and as seen in table 23, it saves a lot of energy but is not performing as good when it comes to reducing water and chemicals. Therefore, the method is not most suitable for IKEA or a company that wants an overall improved environmental sustainability, but for a company that is only aiming to reduce its energy, it is a good choice.

The Airflow dyeing method shows a relatively even reduction of water, energy and chemicals, but does not have the best results in any of the categories. This does not mean that the method is not performing good enough from an environmentally sustainable perspective since a smaller reduction in all categories can result in larger improvements than a method only reducing one category, but in larger volumes. The Airflow method does also have its issues which for example is the risk of uneven color finish. The same disadvantage comes with the ScCO2 method where too little data and knowledge about the dyestuff solubility are found. The benefit with ScCO2 presented by Abate and Tadesse (2021) is that the method is relatively cheap which makes it easier to invest in without being forced to increase prices towards customers or risk decreasing the suppliers own profitability. But even though the method leads to elimination of water and is relatively cheap, it does not fulfill all the requirements within all the categories water, energy and chemicals. For IKEA and many other companies, it is not an alternative to use a method that can not guarantee that the color finish is the same on all items on a specific product line. The issue with uneven color finish would lead to the supplier being forced to produce more textiles and eliminate the ones with an undesired color finish and replace them with new, correct textiles. That results in a waste of water, energy and chemicals which has a bad impact on environmental sustainability. It is also negative from a cost perspective where the supplier will have to pay for production costs without being able to sell the products since the finish is not what the customer wants. That would lead to increased overall costs within the production and the supplier would be forced to increase their selling price of textiles to the customer. As a company buying from the supplier, it is not always possible to keep up with increased costs since that also forces them to increase the selling price to the end customers. That would in the next step risk decreased customer demand and the company's sales.

The Spray dyeing method is the best method in all environmental aspects, water, energy and chemicals as seen in table 23. The latest machines that the company Imogo has developed shows excellent results and are reducing water, energy and chemicals by 90 percent compared to conventional methods. From an environmentally sustainable perspective, there are no issues with this method. The problem lies in more financial aspects including the large investment that the method results in as well as the required machines taking up large facility spaces. Implementing this method would therefore lead to a large cost for the supplier which in turns will result in increased costs for the buying company and finally for the end customers as well. For a company aiming to become more environmentally sustainable it is a good method since it improves the usage of water, chemicals and energy within the wet dyeing process, but it does have a price. For some companies it will be worth it, since their impact on environmental sustainability is so important for the end customers that a change to a method like this is required to keep being competitive in the market (Kerle et al., 2021). For a company like IKEA where cost consciousness and low prices are prioritized, it is a harder decision to implement a method like this. But since IKEA is seen as a reliable customer in combination with buying large volumes, there is a possibility to negotiate with the supplier. Since they often stand for a large part of their suppliers' production, they are important customers that the supplier does not want to lose. Because of this, they have the possibility to recommend that the supplier should collaborate with them and together develop a more environmentally sustainable wet dyeing process through investing in new methods. As both interviewed suppliers were positive about a collaboration between them and IKEA, it could be a good idea to improve the wet dyeing process together. As a supplier it results in being able to implement a method that requires large investments which also eliminates the risk of losing large customers because of not being able to afford a more environmentally sustainable production. For the buying company, e.g IKEA, it would result in a more environmentally sustainable production of their products.

Another option for making large investments easier is the fact that both Supplier two and supplier one communicated that all their customers continuously increase their interest in environmental sustainability and often follow the developments that IKEA does. In that way, the suppliers can present the investment and change of method that IKEA wants to implement to its other customers. Bringing up the advantages and how it would benefit their other customers would possibly lead to many of the other customers also wanting to change methods into the new one, to improve their environmentally sustainable impact. That would in turn lead to the costs being splitted between more companies, which is good from a financial perspective where the risk of being forced to increase their price towards the end customers decreases.

After all, the Spray dyeing method will be a better alternative from an environmentally sustainable perspective compared to all conventional methods. As Lin et al. (2021) presented, the method results in improvements regarding usage of water, energy and chemicals. Even though it requires a large investment which IKEA's two suppliers communicated as a reason why more environmentally sustainable changes were not made within their productions, it will be a good investment. The increased requirements from customers to become more transparent and environmentally sustainable will sooner or later force suppliers as well as the buying companies to create new ways of producing and purchasing products. Implementing the Spray dyeing method will make the company special since alternative methods are not well known and used within the textile industry. The growing interest and environmentally conscious buying behavior among the customers would also result in increased demand for products produced with a more environmentally sustainable method. It would also improve the company's reputation within the environmentally sustainable field. Besides fulfilling requirements from customers, for a company like IKEA, implementing the Spray dyeing method would also take them further to their goal of becoming a circular business by the year 2030.

For IKEA to be able to reach their environmental goals and become a circular business by the year 2030 and in general become more environmentally sustainable, they should really consider implementing a new alternative method. Implementing the Spray dyeing method is the researchers recommendation for improving IKEA and other companies' impact on environmental sustainability within the wet dyeing process. Even though it initially requires a large investment it will be worth it both to continue to offer the products that the customers demand and to stay competitive on the market.

5.2.5 Recommended alternative colorants

There are a lot of alternative colorants on the market that can replace the use of e.g reactive dyes and improve the environmental impact of the coloration process. Natural colorants are one of these and are seen as a more environmentally sustainable choice. There are a lot of different natural colorants since it is made of raw material from nature, for example the marigold flower presented by Baig et al. (2021) and used for yellow colors. They found that using this flower would reduce the dye liquor and sodium chloride within the coloration process. Further on, Baig et al. discuss that using natural colorants would lead to energy savings compared to chemical based coloration.

The global leader within the production of natural colorants is the company Archroma that produces their own natural colorant called "Diresul" which contains different ingredients depending on what color that is produced. According to Archroma (2021), using their color results in 23% less water, 54% less energy and 50% less chemicals compared to conventional colorants. They also claim that the color fastness is good as well as it is suitable for deep shades. It is not only the colorant Alchroma offers, but also liquor for the other processes within the wet dyeing process, e.g pretreatment and finishing.

Patagonia is one of the companies who has been using Archroma's natural colorant in one of their collections. The collection was launched in 2017 and after the production, Patagonia (2017) discovered that the shade was fading and that the color fastness was not as good as desired. According to Campbell (2019), this is one of the problems with natural colorants. Using natural colorants are also more expensive because of the larger quantity required to get the desired color result. As Patagonia discovered, also Campbell (2019) discusses the fact that the color fades quickly. The problem regarding availability is also a disadvantage with natural colorants and for bigger companies producing larger quantities, it is something to consider when analyzing implementation of natural colorants. The availability of raw material needed for natural colorants are often seasonal. For companies producing smaller and seasonal collections of e.g clothes, it could be suitable to base the collection on the most common and available raw material for that season. For a larger company producing large quantities to get economies of scale and in that way keep the costs down, it is less feasible to change ingredients from season to season. For example IKEA's products "Dvala" and "Vågsjön" which are sold all year around in large quantities and different colors are difficult to use natural colorants on. Firstly, the quantity of raw material needed is large as well as the raw material needed for different colors must be available all year around. The availability of raw materials needed differs from e.g season and place. That leads to that the raw material needed for producing the products either is not possible to get alternatively needs to be shipped long distances to the production, which is not suitable for an organization aiming to become more environmentally sustainable. An alternative could be to use these colors on smaller collections of home textiles and use it as a marketing campaign by being transparent with which colors are available for what seasons and why. But as a company it is important not only to look into the environmental impact, but also the costs and quality of the product. It is therefore not profitable to use more expensive colorans that do not reach the color fastness that is required from the customers. That would lead to lower quality in combination with increased costs which is not desirable.

Another more environmentally sustainable alternative of colorant is bacteria. There are both advantages and disadvantages with this colorant. As Nisar (2021) presented, it reduces water, energy and chemicals usage compared to conventional colorants. A common issue with natural colorants, e.g flowers or vegetables, are the restrictive production places and periods. These types of raw material require a certain temperature, in a certain area and during a certain time to grow and become useful. This makes it difficult to provide a company with large quantities with the required amount of color. Coloring with bacteria on the other hand makes it possible to provide large quantities of natural colorants since it is made in the laboratory through biotechnology and can be reproduced whenever. Further on, Nisar (2021) presents that it is more economical than using flowers or other raw materials from nature. Even though it is possible to provide a larger quantity of color when using bacteria, that type of coloration has its own disadvantages. As Luchtman and Siebenhaar (2020) present, the bacterial colorant is not developed enough to be 100% resistant to washing and sunlight. That means that today, it is not guaranteed that a fabric that is colored with bacteria will have the same color one year after its production day. As a customer it is hard to accept that e.g a furniture changes color or loses the deep color that it had when it was purchased. These issues are tough depending on the customer and also what type of product it is and the color the article had from the beginning. E.g a beige couch might not be washed a lot and not necessarily exposed to a lot of sunlight. A bit of fading on an already light and beige color might not either be a problem if it occurs since it is already a natural and light finish. The transparency about the environmentally sustainable colorant will also result in the customer being aware of the possible color fading, but choose to purchase it either way since they want to become a part of the development of a more environmentally sustainable textile industry.

Using bacterial colorants would improve the environmental sustainability in the textile industry with a reduction of water and energy as well as an elimination of chemicals. But even though bacterial coloration has better color fastness than the rest of the natural colorants, there is still some developing work to do for a perfect color finish. As Luchtman and Siebenhaar (2021) discusses, there are still disadvantages with bacterial colorants and to be able to replace current colorants with it, there needs to be improved color fastness and reduced fading of shades during the usage. Using bacterial colorants results in efficiency for companies since it is a cheap and easy colorant that also contributes to textile companies' aim to become more environmentally sustainable. On the other hand, it does not fulfill the customers' requirements since the color fastness is not 100% in combination with fading colors. Yet, Luchtman and Siebenhaar, as well as other companies e.g Colorfix, are convinced that biotechnology and bacterial coloration is only in the beginning of its future impact on the wet dyeing process and its transition into becoming environmentally sustainable. Therefore, as a company within the textile industry it is important to keep up with the developments within this field and also do collaborations with companies and scientists that are working with these colorants to be an early adopter of the most environmentally sustainable colorant yet.

6. Conclusion

The chapter starts with a conclusion for research question 1 followed by the conclusion for research question 2. After that, the researchers' own reflections, theoretical and practical contribution, suggested future research and lastly the contribution to society is presented.

6.1 Conclusion for research question 1: How environmentally sustainable are IKEA's suppliers' wet dyeing process in terms of water, energy and chemicals used?

After ranking the three conventional methods used by IKEA's two suppliers based on water, energy and chemicals, the researchers came to the conclusion that supplier two, that is using Pad-dry-pad-steam, has the largest negative impact on environmental sustainability. Their used method is performing badly in all categories water, energy and chemicals. One of the two methods that supplier one is using, Pigment dyeing, performs best regarding water and chemical usage, but is consuming more energy than the other two conventional methods. The second method used by supplier one, Cold pad batch, is performing better than Pad-dry-pad-steam in all categories, but worse than Pigment dyeing regarding water and chemical usage. This shows that supplier one's wet dyeing process when producing the product Dvala, in general, is more environmentally sustainable than supplier two when producing the product Vågsjön. Yet, this does not mean that supplier one does not need to take any actions to improve their wet dyeing process. The researchers believe that both suppliers can make improvements to become more environmentally sustainable and reduce their water, energy and chemical usage and this is therefore further investigated in research question 2.

6.2 Conclusion for research question 2: What improvements could be done in the wet dyeing process to improve environmental sustainability?

The best solution for a company to make their wet dyeing process more environmentally sustainable is to implement the alternative method called Spray dyeing since it results in a 90% reduction of water, energy and chemicals compared to conventional methods. The issue related to an implementation of this method is that it requires a large investment, but since customers demand products produced in a more environmentally sustainable way, it is worth it to stay competitive on the market.

To improve the environmental sustainability even more, it could also be beneficial to replace conventional colorants with bacterial colorants since it would reduce the negative environmental impact within the coloration process. The issue involved with this is that the developments within bacterial colorants are ongoing and there are still improvements needed before they will be able to completely replace conventional colorants. Currently, bacterial colorants risk to result in uneven color finish and bad colorfastness. As a company it is therefore not possible to replace all their current colorants with bacterial colorants today, but as a step forward to become more environmentally sustainable, it is a good idea to actively be a part of the development of the colorant since it is said to be the future of coloration.

6.3 The researchers own reflections

The researchers have not been measuring the data themselves, but received it from the two chosen suppliers and chose to trust the information given. That makes it more difficult to ensure that all data received from the suppliers are totally correct and truthful compared to if the researchers would collect the data directly from the production. The assessment is made that the data received from the suppliers are relatively near the reality which also is supported by the theoretical sources found. In that way, the information from the empirical chapter can be considered as reliable enough to be an interesting contribution for further analysis and conclusion regarding environmental sustainability within the wet dyeing process.

The data received from the suppliers regarding water, energy and chemicals was not measured in the same units, e.g per kilogram of fabric. Because of that, it is harder to compare the different methods that the two suppliers are using. The researchers would therefore recommend, for improving further development work within the wet dyeing process, that IKEA requires that their suppliers measure and share all data of energy, water and chemicals for each kilogram of fabric. Even though this data was not received, the measurement grams per liter in combination with milliliters per kilogram of fabric is usable for making a relevant analysis and conclusion of the conventional methods used today.

6.4 Theoretical and practical contribution

The researchers are contributing with theoretical material by comparing different conventional methods and colorants based on their impact on environmental sustainability. This is later on compared to alternative methods and colorants which results in increased understanding of how new methods and colorants on the textile market can improve the wet dyeing process. Companies aiming to improve the environmental impact of their wet dyeing process can therefore use this thesis to increase their knowledge regarding water, energy and chemicals used within both conventional and alternative methods. Based on that, they can take a decision of which method and colorant that is the most suitable for them to implement to improve their impact on environmental sustainability.

The practical contribution by this thesis is the collected data containing the usage of water, energy and chemicals in three different conventional methods within two of IKEA's largest textile suppliers' wet dyeing processes. Other companies using any of these methods can use the collected data to compare their own water, energy and chemical usage and see if they can improve any of these categories according to IKEA's wet dyeing process. Further on, companies can compare the amount of water, energy and chemicals that each method uses to be able to choose the most suitable one depending on which of these three categories they are aiming to reduce.

6.5 Future research

The researchers of this study suggest that a future research could be to investigate more of IKEA's textile suppliers and their wet dyeing processes to identify possible improvements within water, energy and chemicals. By looking into more suppliers and more products within their textile assortment, IKEA will get closer to reach their environmental goals that they have set up to year 2030.

Another suggestion on future research is to investigate the wet dyeing process within other companies than IKEA to be able to compare how different companies work with their water, energy and chemicals. It would also result in even more reliable empirical data since it would be based on more suppliers than the two that are used in this thesis.

The researchers only focused on the wet dyeing process, due to the limitation of the thesis. The last example of further research is therefore to look into the whole order-to-delivery process of Dvala and Vågsjön to see what improvements that could be done to make the whole production process more environmentally sustainable.

6.6 Contribution to society

The thesis is contributing to society by giving an increased understanding of how much water, energy and chemicals that are used in the wet dyeing process when producing textile products. Many customer's buying behavior are expected to change with increased understanding of e.g the amount of chemicals that are needed to produce one specific textile product and how negatively that affects the environment. This thesis contributes to increased awareness regarding the water, energy and chemicals used within the textile industry and its negative influence on environmental sustainability. This might result in society reflecting once more before purchasing a new textile item.

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8. Appendix

8.1 Interview questionnaire

1. About you as a supplier

1.1 How many employees are there in your production facility?

1.2 Where are you located and how big is the production facility?

1.3 Are there a lot of unused space in the facility or do your current equipment and machines take up all the space?

1.4 For how long have you been working with IKEA?

2. About the production process of IKEA's products

2.1 What does the wet dyeing process look like from start to end for Vågsjön/Dvala?

2.2 Are different shades produced in different ways, e.g one method for light shades and one method for dark shades? If yes - why?

2.3 What colorants are you using and why?

2.4 What is the consumption of water, energy and chemicals per kilogram of fabric for each specific method, from the pretreatment process to the finishing process?

2.5 Do IKEA work actively with you to develop the wet dyeing process into becoming more environmentally sustainable?

2.6 What are the difficulties with improving your wet dyeing process when producing textile products?

2.7 How are you purchasing the material used in the production of Dvala/Vågsjön?

- How can you guarantee IKEA that the sub-suppliers are also following the IWAY?

3. About the production facility in general

3.1 Are IKEA's production line(s) separated from your other customers' production lines?

3.2 How is the sectioning in the production between your different customers? How much of the production is used for IKEA's products? E.g 20%, 50% etc.

4. About possible future improvements

4.1 Have you detected an increased interest among your customers to improve the environmental sustainability of the production of their products?

4.2 Do you have any upcoming developments in your production e.g an investment in a new machine or implementing a new method?

4.3 Are IKEA the most developed company among your customers regarding environmental sustainability, or are there others that are ahead of them in terms of water, energy and chemical usage within the wet dyeing process?