Sustainability Project Final Report
Sustainability Minor

Promoting Sustainability in the Luxury Fashion Industry: A Closer Look at the Biella Province

by *DR, SS, CP, JB*

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Introduction

Fashion has modelled the way individuals dress and express themselves for centuries. However, industrialization and the rise of mass consumerism, witnessed in the last century, catapulted the fashion industry to a multibillion-dollar industry (Shishoo, 2012). Higher and more diverse consumer demand pushed firms within the industry to find ways to produce more clothes at a faster rate to fit the ever-changing fashion trends (Cabigiosu, 2020). As the industry modernised, companies also found ways to produce more cost-efficiently, leading to a clear separation within the fashion world: affordable vs. luxury fashion. The more affordable brands focused on providing a wide variety of items for as cheap a price as possible. Meanwhile, luxury brands separated themselves from ordinary fashion by promoting high quality products made using timeless techniques and the best products available (Cabigiosu, 2020). This gave Italian brands a helpful edge considering the history of the fashion industry in the country. Nowadays, most world-recognized luxury fashion brands come from Italy. With its seemingly sustainable and timeless image, the luxury fashion world has managed to stay relatively out of reach of media criticisms of the fashion industry (Okonkwo, 2007). Yet their production process remains just as harmful as that of other brands. The use of chemicals in the wet processing of textile can lead to water pollution and release toxins harmful to both humans and nature (Palacios-Mateo et al., 2021). One province in northern Italy, Biella, is specially known for its high-quality wool catering to the luxury fashion world, but very few sustainable efforts seem to have been made there (Radetic et al., 2007). For this reason, this report will investigate by answering the research question "**How does the wet processing of wool in Biella impact its environment, and to what extent can this process become more sustainable?**".

The report first assesses the problem at hand through a literature review looking at the historical background of Biella, the environmental impact of its current processes, and some already-implemented solutions in the province. With the help of this literature, the report then forms an Environmental Assessment of Biella's dyeing and finishing, the last two steps of textile wet processing. Several alternatives derived from this Assessment are presented in this report before providing the final recommendations for Biella's textile industry. All steps of this report can be related to several SDGs: SDG6, clean water and sanitation; SDG9, industry, innovation, and infrastructure; SDG12, responsible consumption and production; and SDG13, climate action.

These SDGs are present within every step of this report. The environmental impacts such as water usage or chemical toxicity can be directly related to SDGs 6 and 13 for their impact on the environment. The alternatives discussed as part of this report's environmental assessment can be categorised under SDGs 9 and 12, as the Italian luxury fashion industry attempts to edge closer to sustainable production processes (United Nations, 2023).

Literature Review

The history of textiles in Biella, Italy

While many of the textiles used for mainstream brands are outsourced abroad, luxury brands appeal to their customers by promising textiles from local, high-quality producers. For many Italian luxury clothing brands, the province of Biella provides the highest-quality wool available (Consorzio Biella, n.d.; I.T.B., n.d.). Biella is known for its high-quality textiles for centuries, dating back to Roman times. The geographical placement of Biella played a crucial part in the province's success. Textile production requires a large amount of water supply available to wash and prepare the products. Biella is home to many small streams which provide all the necessary irrigation for these processes. In addition, Biella provides ample space and plains for sheep to be kept, whose wool will be used in many of Biella's textiles (I.T.B., n.d.). As Bella's notoriety grew, more and more small family businesses came together under a single entity, the Biella Wool Company (Consorzio Biella, n.d.). With the continued growth of the fashion industry, the Biella Wool Company was no exception amongst the hundreds of other companies adjusting their production processes to adapt to an ever-growing consumer demand. While diversifying their products and increasing the frequency of new item drops, Biella worked to improve its image by putting forward its history of textile. The province kept pushing the "Made in Italy" label forward as a sign of timeless quality and luxury associated with a fully homemade, natural process. When buying wool from a Biella-based company, the customer automatically assumes that the high price is due to the careful, harm-free process of designing the final product. However, when looking at the wet processing of wool, these expectations are clearly not respected (Radetic et al., 2007).

Environmental Impacts and the SDGs

The clothing industry, luxury fashion included, has had many negative impacts on the environment, namely water pollution, and health hazards for both workers and consumers. Wool, a material collected from sheep, is a natural fiber, and therefore does not have the same impacts of synthetic textiles made from crude oil which must be extracted and spun into fibers, emitting greenhouse gases, and creating hazardous conditions for workers (Palacios-Mateo et al., 2021). Sheep wool still goes through a variety of impactful processes before it is a finished product. This report focuses on the wet processing of wool as it is considered to be one of the most harmful steps of the textile production process (UNEP, 2020). Wet processing consists of a variety of steps that are applied to the textiles depending on the type of textile and desired outcome. Common processes are scouring, bleaching, dyeing, and finishing.

This report focuses on the last two steps, dyeing and finishing, as research has shown them to have the worst impacts on the production's overall sustainability (Li et al., 2011). Dyeing produces a number of undesirable outcomes from an environmental and social perspective, because synthetic dyes can be toxic, associated with cancer, and can be released into the environment into bodies of water (Palacios-Mateo et al., 2021). A study by Birhanlı and Ozmen (2005) showed the toxicity of six different types of synthetic dyes on frog embryos. While not all dyes were equally harmful, all made the embryos teratogenic (malformed). As frog embryos develop in water, and it has been established that clothing production produces high amounts of wastewater, it is possible that other water species could be impacted by the use of synthetic dyes (Birhanlı & Ozmen, 2005). Additionally, in 2014, France established that the twenty-two dyes and twenty-five dyes used in a textile factory were harmful, toxic, water polluting, and carcinogenic (Starovoytova, 2014). Another chemical used in the dyeing process is (metal salt) mordant which ensures that the fabric will hold the dye, and that the colour will remain as vibrant as desired (Shahid-ul, et al., 2018). The wastewater from the process of mordanting contains high levels of heavy metal toxicity, which poses a threat to aquatic plant life and human health (Reddy & Osborne, 2020).

Finishing, the following process, is applied to fabric in order to soften or give the fabric other desirable qualities (Palacios-Mateo et al., 2021). Finishing agents can also be toxic for the health of workers, and if leaked into the environment, the surrounding populations (Palacios-Mateo et al., 2021). After the textile is completed, it is cut and sewn together, often leading to fabric waste and micro-fiber air pollution. (Palacios-Mateo et al., 2021). The fashion industry has an obligation to its customers to ensure products have no defects. This obligation becomes greater for the luxury fashion industry, where quality is the number one priority for both producers and consumers. Any fabric with minor defaults needs to be discarded. Not only does this create wasted fabric, but also a waste of chemicals and dyes used during wet processing. In 2016, Italy was ranked by the European Union as the largest textile waste producer in the EU with almost 467 metric tons of textile wasted (LabFresh, 2016; Smith, 2022). The finished garments are then shipped to stores, releasing harmful amounts of greenhouse gases (Palacios-Mateo et al., 2021).

Current Innovations and Approaches

While the luxury fashion industry poses several serious environmental and health concerns, efforts to improve sustainability within the industry have already been made. Despite its high waste levels, Italy has made major breakthroughs already with individual and corporate initiatives. The concept of eco-efficiency is already being discussed in several Italian fashion hotspots, including Biella (Angelis-Dimakis et al., 2016). Introduced in the 1990s, eco-efficiency follows the basis of "less is more" by using resources more efficiently, creating less waste and pollution using less materials while still producing similar quantities (Muthu, 2020). The article by Angelis-Dimakis et al. (2016) uses a Life-Cycle Impact Assessment (LCIA) to investigate the environmental impacts Biella's textile industry had on the province. The main findings of this article were that there was freshwater source depletion and toxicity due to water-intensive processes like in the wet processing, specifically during dyeing and finishing, concluding that the province would highly benefit from implement eco-efficiency (Angelis-Dimakis et al., 2016).

Biella's pursuit of sustainability does not stop at eco-efficiency. Two fashion businesses in the province have started to explore how to make sustainability profitable. One of the key barriers to implementing more sustainable practices are the potential costs incurred as well as lack of knowledge. Bernardi et al. (2022, p. 121) argue that sustainability becomes beneficial on the condition that "strong corporate values, cultural heritage and stable relationships [are maintained] with the territory". This is highly applicable to Biella and the rest of Italy, as the unique craftsmanship and fashion industries are integral to the heritage, culture, and identity of particular regions and provinces. Italian luxury products are often made by a variety of smaller (sometimes family-owned) factories and businesses. Within these smaller factories, the value and preservation of the land and culture is held in high regard (Bernardi et al., 2022).

Another initiative born in Biella is the Ecotec project (EMCC, 2013). Ecotec was launched following a desire to turn the Italian textile world into the industry's leader in sustainability by fabricating cotton using recycled yarn. The company collects leftover or discarded pieces of cotton, cuts and breaks them down, and then combines them to make new cotton yarn. This alternative has already been successfully implemented in the region, providing the researchers with real-life evidence of the benefits of orienting the textile industry towards more sustainable approaches, aligning with the general purpose of this paper (EMCC, 2013).

These initiatives show that progress is gradually moving forward in the Biella province, which provides this report with solid grounds and data for an environmental assessment, as they identify several environmental issues arising from the fashion industry in Biella. Furthermore, this identifies a research gap within the industry: while assessments were performed for cotton and water use, wool production was underrepresented in Biella, further motivating the researchers to turn their attention towards wool for this report.

Environmental Assessment

With a goal of finding ways to promote sustainability in Biella, and limited resources, an environmental assessment was the most feasible option for methodology. An environmental assessment is one preliminary step in a larger process which means that they are often done quickly and with more limited resources (US DOE, n.d.). Given the time constraints and lack of data-collection resources of the researchers, there was a decision made to use an environmental assessment. Environmental assessments are conducted so that decision-makers can understand the significance of an action's impact on the environment and can inform whether to do further assessment (US DOE, n.d.). Each step of the assessment provides a format to understand the current state of the environment in an area, and the impacts that various alternatives would have on this environment. With this information, decisions can be made for future research. The outcome of an Environmental Assessment is normally a statement of Finding of No Significant

Impact (FONSI) or a decision to create a more detailed Environmental Impact Statement (EIS) (US DOE, n.d.).

The Federal Emergency Management Agency of the United States (FEMA) assembled a clear and applicable format that the following assessment will adhere to. There are four main components to an Environmental Assessment (FEMA, 2020). The first component provides context and background, with a description of the current environment and current damages (if there are any). Additionally, the 'purpose' and 'need', meaning the 'goal' and 'problem' are stated. The second component consists of descriptions of each alternative, one of which is an alternative of "no-action", meaning that no new changes are made that have not already been decided. The third component consists of the descriptions of the environment that would be impacted, and the specific impacts of each alternative. The fourth component is a summary of the alternatives discussed and the pertinent information (FEMA, 2020).

This environmental assessment, while following most of the structure laid out by FEMA, does not follow every part of this structure, especially in the third component and fourth component. The third component of this assessment more broadly discusses the impacted environment of each alternative (focusing mostly on water quality, toxicity and energy-use), rather than all individual aspects of the environment. The fourth component, the summary, will be included in the conclusion of this paper. Despite these changes, this form of assessment still allows for understanding the current situation (the Biella wool industry) and for analysing and assessing potential ways to reduce environmental harm.

Location and Background

The province of Biella is well-known for the quality of products in the Italian luxury fashion industry, specifically the wool industry (The Compass, 2016). Around 650 textile factories are established in the area (Angelis-Dimakis et al., 2016), which are significant for the local economy and have been important to the authenticity of the industry, due to the use of conventional practices for wet-processing. The geographical characteristics of Biella are beneficial and necessary for the wet processing of wool. This makes the industry reliant on the environment (The Compass, 2016). One of the geographical characteristics is the location. Located in the north-west of Italy, the province of Biella is near the Alps (The Compass, 2016). From the Alps, multiple waterways run down the mountains through the area. Companies are reliant on the water basins from the Po river and the Cervo river. The water that runs here is considered hard water that contains calcium and magnesium (The Editors of Encyclopaedia Britannica, 2022). This composition of water quality adds to the quality of the wool. Therefore, the geography including water access and water quality is considered a beneficial factor to the Italian luxury fashion industry of Biella.

Especially with the focus on the intense wet-processing, dyeing and finishing, of wool, the nearby water basins play an important role (The Compass, 2016). However, this water easily gets polluted by the industries located in the area. This includes excessive use of water leading to freshwater depletion. Furthermore, chemicals used during the dyeing and colouring process have detrimental effects on the water and surrounding environment (Angelis-Dimakis et al., 2016). Figure 1 (Meffe & de Bustamante, 2014) shows a map of industrial pollutants on a national scale. The researched region (in the Northwest) is located within the polluted regions, meaning the Italian luxury industry is a contributor to polluting the environment.

Figure 1.

Industrial pollutants Italy

Note. Adapted from Meffe, R., & de Bustamante, I. (2014). Emerging organic contaminants in surface water and groundwater: a first overview of the situation in Italy. *Science of the Total Environment*, *481*, 280-295. P.282.

More recently, the local government has been implementing initiatives for economic progress, as Biella has been suffering from a crisis for the last couple of years (Angelis-Dimakis et al., 2016; La Città…City Fashion, 2021). Since the COVID-pandemic, local companies have struggled with keeping their doors open because of decreasing customer base and the lack of economic stability.

This has forced a selection of the textile companies to close (Angelis-Dimakis et al., 2016). In the scope of sustainability, the local government of Biella has been investing their time and money into the perseverance of local companies (La Città…City Fashion, 2021). The local initiatives have therefore primarily been aimed at supporting or regenerating the economic resilience of the local economy. However, no specific alternatives have been mentioned to achieve this goal. One example is the 'Green Deal City Fashion'. This is a project set up by the municipality of Biella to protect the industries and their history, specifically the wool industry. The aim is to make the shift to a circular economy by investing in innovative and sustainable development (though these are not specified) (La Città…City Fashion, 2021).

Purpose and Need

The purpose of this environmental assessment is to improve the sustainability of the wool industry in Biella. The need of this assessment is to lessen future risks to the environment.

Alternatives

Table 1.
Summary of Alternatives

Alternative #	Name	Summary Action
1	No Action	Current methods, impact and policies will continue, no changes are made
2	Proposed Action	Combination of Alternative 3 and 4
3	Natural Dyes & Bio-Mordants	Combined with 4 for Proposed Action
4	Electrochemical Treatment	Combined with 3 for Proposed Action

Note. (Format of Table (Robbins et al., 2021)).

Alternative 1: No Action

In order to fulfil our assessment method, alternative options are needed in order to achieve a more sustainable wool industry in the province of Biella. These different alternatives are focused on innovation, sustainability, and environmental impacts. The first alternative is the alternative of no-action. No-action encompasses the continued use of the current wet-processing methods and the implementation of the current initiatives. No additional processes or changes or new policies will be made to the industry or this part of the supply chain.

Alternative 2: Natural Dyes & Bio-Mordants

Alternative 2 is the implementation of the use of natural sources for the traditional chemicals used in the dyeing processes in wool industrial units found in Biella. Natural dyes would replace synthetic dyes which are currently being used in the wool textile industry (Angelis-Dimakis et al., 2016). Natural dyes are sourced from a variety of materials, such as minerals, animals, leaves, shells of some fruit, vegetables, and other plants (Rather et al., 2019). Some examples are the madder and reseda plants, Neem Tree bark, and shells of nuts such as coconut, macadamia nut, almonds and walnuts (Ali Khan et al., 2016; Dulo et al., 2020; Erdem İşmal et al., 2015; Hosseinnezhad et al., 2021; Tian et al., 2022). Natural materials, such as walnut shells, can also replace metal salt mordants (these are called bio-mordants) (Hosseinnezhad et al., 2021).

Due to their natural sources and compositions, these dyes and bio-mordants are non-toxic and biodegradable (Shahmoradi Ghaheh et al., 2014, Imani et al., 2022). For these reasons, they do not impact the environment in the way that synthetic dyes do. The use of natural dyes and bio-mordants address the purpose and need of the environmental assessment because this alternative does not lead to effluent containing heavy metals and carcinogenic and toxic agents (Lellis et al., 2019). Additionally, the natural dyes and mordants can be applied to textiles and provide properties such as anti-bacterial, anti-moth and provide UV protection for wearers (Dulo et al., 2020; Rather et al., 2019; Tian, et al., 2022).

Natural dyes and bio-mordants could be used in the Biella wool industry. Many of the natural dyes and bio-mordants have been specifically tested on wool (Hosseinnezhad et al., 2021). Two sources for natural dye that are particularly relevant for the case of Biella is the shell of walnuts and almonds, which can produce hues that range from light reddish-brown to extremely dark brown (Gomez-Moreno et al., 2022; Hosseinnezhad et al., 2021). Walnut and almond shells are an example of agro-waste, a natural by-product of the agricultural industry that would most likely be sent to landfill or burned (Dulo et al., 2020; Gomez-Moreno et al., 2022). Walnuts and almonds are both grown in Italy, and their shells can be used both for dyeing as well as mordanting wool (Di Pierro et al., 2022; Gomez-Moreno et al., 2022; Hosseinnezhad et al., 2021). In order to implement this alternative, factories would need to change where they decide to source their dyes from. Alternatively, some of the dyes, including walnut shell dye, can be made on-site by combining water with powdered walnut shell (Ali Khan et al., 2016). Once they have decided on the source and suppliers of dyes as well as the range of colours that are appropriate for their desired products' appearance, each factory could transition the production line or employ the use of a separate production line (Angelis-Dimakis et al., 2016).

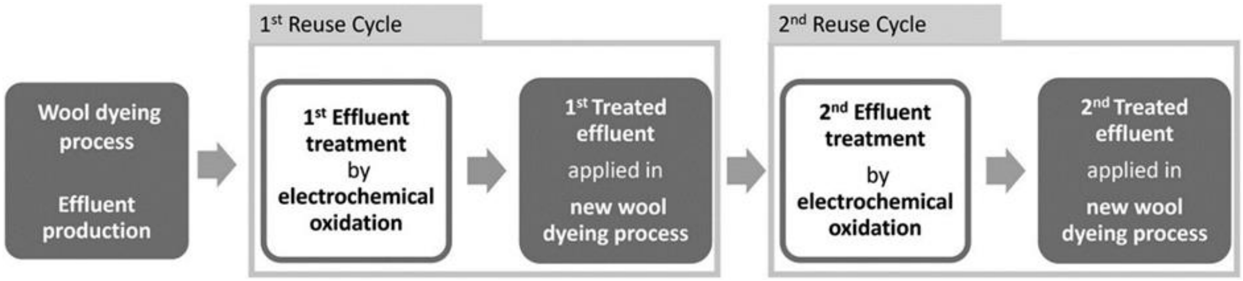
Implementing natural dyes in the wool industry would incur costs as well as savings. The economic cost of using natural dyes may be higher than use of synthetic dyes in the wool industry (Ali Khan et al., 2016). But individual factories may be able to sell their dyed products for a higher price because of the use of natural dyes (Angelis-Dimakis et al., 2016). Additionally, factories may save money on energy-costs and potentially on water-use (Angelis-Dimakis et al., 2016). Some other challenges to implementing this alternative may be the lack of colour range and current use of natural dyes. While natural dyes have the potential to achieve a larger variety of colours, research has not been done on a large variety of colours that would be commercially viable options for wool.

Alternative 3: Electrochemical wastewater treatment

This alternative proposes the utilisation of electrochemical treatment plants to treat the contaminants found in wastewater effluent from the dyeing facilities. Electrochemical treatment uses electricity as a main reactant to treat contaminants found in wastewater (Sillanpää & Shestakova, 2017). There are several advantages to this alternative, the largest being its ability to save resources that are used in wet-processing and treat water from the dyeing and finishing processes (Brillas & Martinez-Huitle, 2015). Additionally, this technology can cut down on the use of salt additives in the wool dyeing process (Pinto et. al, 2022).

Figure 2.

How wastewater is treated through electrochemical oxidation

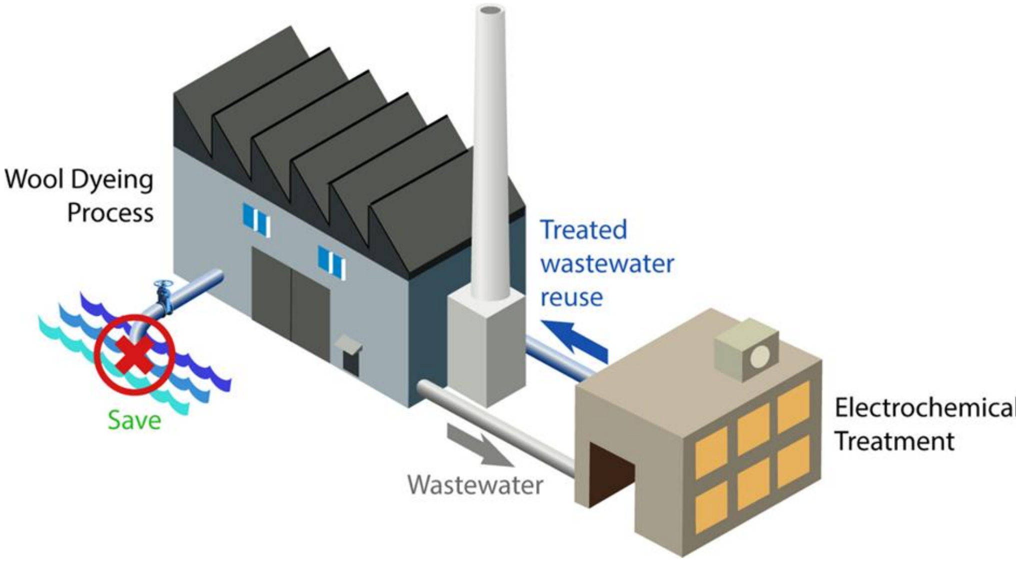


Note. Adopted from Pinto, C., Fernandes, A., Marques, A., Ciríaco, L., Miguel, R. A., Lopes, A., & Pacheco, M. J. (2022b). Reuse of wool dyeing wastewater after electrochemical treatment at a BDD anode. *Journal of Water Process Engineering*, *49,* 102972. https://doi.org/10.1016/j.jwpe.2022.102972

The alternative addresses the purpose and need through two main advantages. The first advantage is an implementation advantage, which includes energy efficiency, the ability to be automated, easily handled, and safe (Brillas & Martinez-Huitle, 2015). Energy efficiency is possible through the full recovery of additives such as salts, cutting down on costs and resource use (Pinto, et. al, 2022). Automation is due to the ease of operation, easy handling given the simplicity of the equipment needed, and safety given that the operation of electrochemical plants is done under lenient conditions (Brillas & Martinez-Huitle, 2015). The implementation and operation of these plants are easy if the right financial goals are met.

Figure 3.

Electrochemical treatment process of wastewater from wool dyeing (visualised).



Note. Adopted from Pinto, C., Fernandes, A., Marques, A., Ciríaco, L., Miguel, R. A., Lopes, A., & Pacheco, M. J. (2022b). Reuse of wool dyeing wastewater after electrochemical treatment at a BDD anode. *Journal of Water Process Engineering*, *49*, 102972. https://doi.org/10.1016/j.jwpe.2022.102972

The second main advantages are the environmental advantages, which fall under four main areas: the ability to treat multiple types of contaminants, on-site production, the flexibility of the facilities, and possible energy recovery (Chaplin, 2019). These terms are rather broad and understanding them deeper is important. Treating multiple types of contaminants refers to how electrochemical plants are not limited to only treating one specific contaminant but are able to treat a variety from the various steps of wet-processing (Chaplin, 2019). On-site production allows for a decrease in transportation of potentially hazardous materials out of the dyeing facility. Flexibility refers to how electrochemical plants are modular, meaning that their parts can easily be swapped out and replaced to adapt to future situations (Chaplin, 2019). Lastly, energy recovery, which is one that needs more research within the literature, however, has shown that if implemented correctly, energy recovery from electrochemical cells in the form of fuels is possible (Chaplin, 2019).

Before implementing electrochemical plants, relevant individuals in the textile industry will need to inquire about its feasibility and necessity. The feasibility and need look at costs, energy demands, development, and the potential consequences (Chaplin, 2019). Electrochemical plants are demanding both financially and energy-wise, and analysing the cost-benefit would be an important step in implementation. However, the potential consequences of electrochemical oxidation are that it can potentially lead to the formation of toxic organic and inorganic byproducts (Chaplin, 2019). The research is still young, and must be continued further, however, these considerations should be kept in mind when operating these facilities.

Alternative 4: Proposed Action

Alternative 4, the proposed action, is a combination of alternatives 3 and 4. Using both natural dyes, bio-mordants and electrochemical treatment could have a larger collective impact than using just one. While the use of natural dyes and bio-mordants would decrease the toxicity of wastewater when compared to using synthetic dyes, the electrochemical treatment would increase its safety even further. Additionally, the electrochemical treatment can remove some of the toxic chemicals that may be used in the other stages of wet-processing that alternative 3 does not address.

Impacts of Alternatives on Environment

Alternative 1:

In order to adapt to the current environmental impacts, the primary polluters have to be identified in order to act on them. In Biella, Angelis-Dimakis et al. (2016) concluded that the main drivers of environmental harm were ecotoxicity and freshwater depletion. Conventional wet-processing methods use chemicals and heavy metals for dyeing and colouring, which contaminate the surrounding waters and create a toxic environment for humans, aquatic, and terrestrial life. Additionally, wastewater produced during the dyeing and finishing processes is disposed of in the environment (Angelis-Dimakis et al., 2016). Consequently, the industrial chemicals pollute the water and can cause harmful effects for both human health and aquatic life (Meffe & de Bustamante, 2014). Implementing alternative 1: no action means equal environmental impact trends will continue. As an increase in damage to the environment has been established, it is expected that this increase will keep on developing in the future. This alternative will have a significant impact on the environment.

Alternative 4: Proposed Alternative

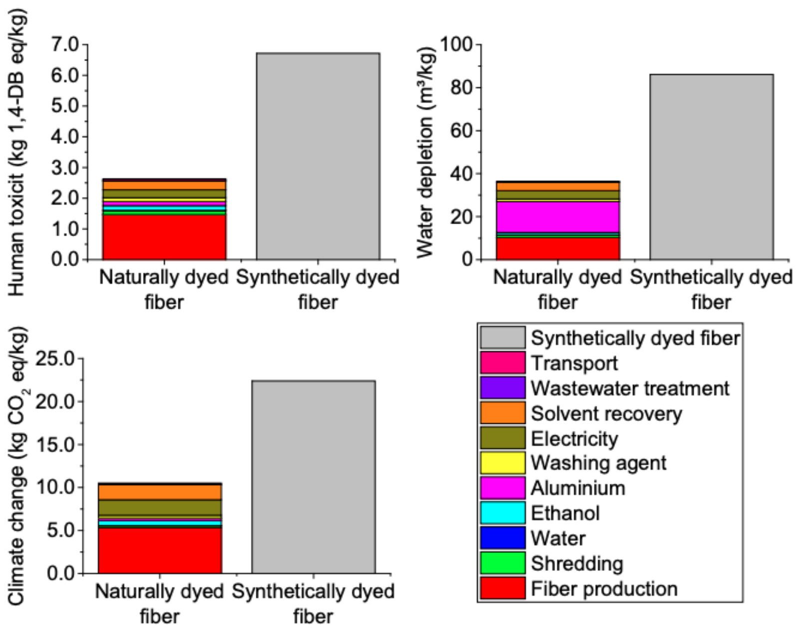
Using both natural dyes, bio-mordants and electrochemical treatments will impact the environment, mostly in positive ways regarding water contamination and emissions.

The electrochemical treatment facilities can have environmental impacts such as cutting down on freshwater use for dyeing, less chemicals in the environment, and less additives, such as salt, which reduces water use in dyeing baths (Pinto, et. al, 2022). Additionally, they create a more sustainable wet-process by treating the contaminants found in the wastewater (Brillas & Martinez-Huitle, 2015). Furthermore, emissions can be reduced because these facilities are on-site, meaning transportation is not needed for the movement of wastewater to other sites (Chaplin, 2019). Overall, electrochemical plants aim to reduce the number of resources used in the textile facilities and attempt to create a more sustainable form of production, however there are considerations that should be taken into account regarding the potential for formation of harmful by-products (Chaplin, 2019).

The implementation of natural dyes and bio-mordants in the Biella wool industry would also have a variety of positive impacts on the environment. The use of these natural dyes and bio-mordants would alter the effluent and wastewater from the process. Natural dyes and bio-mordants do not contain the same amount of heavy metals and toxic agents as synthetic dyes and metal salt mordants (Jabar et al., 2022). Heavy metals have negative effects on the environment and health, such as building up in fish tissue, and potentially, being consumed by people and causing serious health consequences such as liver malfunctioning and central-nervous system disorder (Lellis et al., 2019). The use of bio-mordant would prevent further increase of the load of heavy metals in the effluent from the factories that may flow into the various waterways of the Biella province. Additionally, the amount of human toxicity would be reduced by using natural dyes (as seen in figure 4) (Dulo et al., 2020). Using natural dyes may also not inhibit plant-growth around bodies of water, as synthetic dyes do, often reducing plant growth and photosynthesis (Khan & Malik, 2018; Lellis et al., 2019). Furthermore, using natural dyes would reduce the amount of carbon dioxide emitted and the water used in the process (as seen in figure 4) (Dulo et al., 2020). Using both alternative 2 and 3 together would prevent toxic chemicals from being used in the dyeing process and reduce the amount of toxic effluent in wastewater as a result of the finishing process. Overall, implementing the proposed alternative would address some of the impacts of the two hot-spot processes, dyeing and finishing, in the Biella wool industry.

Figure 4.

Effect of dyeing 1kg of fabric using agro-nut waste extract and the breakdown of the different processes included in the analysed value chain.



Note. Adopted from Dulo, B., De Somer, T., Phan, K., Roosen, M., Githaiga, J., Raes, K., & De Meester, S. (2022, 2022/12/01/). Evaluating the potential of natural dyes from nutshell wastes: Sustainable colouration and functional finishing of wool fabric. Sustainable Materials and Technologies, 34, e00518. https://doi.org/https://doi.org/10.1016/j.susmat.2022.e00518

Conclusion

This report strove to answer the research question "**How does the wet processing of wool in Biella impact its environment, and to what extent can this process become more sustainable?**" by performing an environmental assessment on the dyeing and finishing steps of textile wet processing in the province of Biella, Italy. With the help of the assessment and data acquired from an extensive literature review, the researchers were able to formulate 4 alternative solutions for the province: No Action, Natural Dyes and Bio-Mordants, Electrochemical Wastewater Treatment, and the Proposed Action which mixes Alternatives 2 and 3 together for the most optional results. The implementation of natural dyes, bio-mordants and electrochemical treatment in the wool industry of Biella could have many positive impacts. From both an environmental and economic standpoint, there would be benefits, such as reducing the toxicity of wastewater while simultaneously improving its safety with the electrochemical treatment. Implementing this alternative could significantly improve Biella's overall sustainability as well as reduce any harmful impacts to its environment and inhabitants.

There are however limitations to both the conclusions of the environmental assessment and the proposed alternative. The time and geographical constraints of this report made it impossible for the researchers to acquire sufficient data to conduct a full-scale environmental assessment. Additionally, there is a lack of research and information on the logistics of implementing the use of natural dyes for commercial purposes in industrial environments. These limitations impact the accuracy of our proposed alternative to some extent. Additionally, the colour range available from natural dyes is somewhat more limited than synthetic ones, requiring adjustments from textile companies. This is likely to increase overall costs as well as lengthen the implementation of the proposed alternative in Biella.

Overall, luxury and smaller-scale clothing production can act as a role model for mass-production clothing brands, meaning that if luxury clothing production implements sustainable practices, this could become more mainstream, and have a trickle-down effect into the mass-production clothing industry (Kunz et al., 2020). Focusing on improving practices within the luxury realm could have positive effects on other parts of the fashion industry as well. Therefore, this environmental assessment offers a basis for which future research can be based on. It highlights the prevalent issues within the textile industry of wet-processing and the adverse environmental effects. However, it should not be seen as a final solution. There is a need for future research which enables these alternatives to be realised as well as explore different options within the industry.

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