Faculdade de Engenharia da Universidade do Porto

Energy and Circular Economy based Improvements towards Carbon Neutrality and a Sustainable Future in an International Sports Company

Tomás Miguel Cardoso dos Santos Raio

U. PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Mestrado Integrado em Engenharia Mecânica

Supervisor: Eduardo Gil da Costa

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Abstract

Human civilization has been growing in numbers for centuries, but never as fast as after the Industrial Revolution thanks to the use of fossil fuels and the invention of machinery that allowed for greater and more efficient extraction of natural resources and consequently the development of nations. As lifestyles were increasing, the production of goods grew exponentially worldwide to meet the demand and the industry became faster, more massive, and highly profit-oriented. Throughout this time questions around waste management, resource depletion, and greenhouse gas emissions into the atmosphere were neglected by almost every country. Today, in the year 2021, with little surprise the entire world faces severe environmental issues including the most worrying one - global warming.

The ones contributing the most to this planetary crisis are the rich countries, where some governments and corporations are already starting to elaborate and implement regulations and measures to meet the goals of the Paris climate agreement.

This Master's Thesis project was conducted at the Portuguese Decathlon Department of Production inside the Footwear Industrial Division with the following objectives:

- Identify critical environmental issues in the supply panel;
- Formulate and test solutions towards sustainability;
- Assess the overall gains and challenges.

The initial environmental evaluation exposed the two biggest sources of environmental damage in the supply panel: electricity consumption and waste disposed of in landfills. Therefore, a strategy around energetic transition to renewable sources was put into practice together with two circular economy initiatives to reduce and eliminate the environmental impacts related to electric power consumption and the dumping of valuable waste material.

The adopted strategy towards "cleaner" energy consumption was divided into three priorities that comprised the shift to electricity contracts that provided 100% electricity from renewable sources and the installation of onsite photovoltaic panels. Overall, the supply panel achieved a reduction of 40 metric tons of CO2e emissions per month, a drop of 15% from the initial value.

The two circular economy initiatives concerned tanned leather and PVC waste, and proved to bring not just considerable reductions in terms of environmental impact, but also significant financial savings. When implemented, the project concerning the leather waste in the best scenario will be able to avoid 3.7 metric tons of CO2e emissions and save €22,000, annually. While the recycled PVC project is estimated to avoid the emission of 92.7 metric tons of CO2e into the atmosphere annually, and financial savings of €149,000.

Keywords: Emissions, Environmental Sustainability, Energetic Transition, Circular Economy.

Resumo

Melhorias baseadas em Energia e Economia Circular no alcance da Neutralidade Carbónica e de um Futuro Sustentável numa Empresa de Desporto Internacional

A população humana tem vindo a crescer nos últimos séculos, mas nunca de forma tão rápida como após a Revolução Industrial graças à utilização de combustíveis fósseis e à invenção de máquinas que permitiram uma maior e mais eficiente extração de recursos naturais e, consequentemente, o desenvolvimento de nações. Com o aumento dos estilos de vida, a produção mundial de bens cresceu exponencialmente para satisfazer a procura e, portanto, a indústria teve de se tornar mais rápida, massiva e altamente orientada para a obtenção de lucro financeiro. Durante este tempo, questões como a gestão de resíduos, o esgotamento de recursos naturais e a emissão de gases com efeito estufa para a atmosfera foram negligenciadas por quase todos os países e, no presente ano 2021, o mundo enfrenta graves problemas ambientais, incluindo o mais preocupante de todos - o aquecimento global.

Os países que mais contribuem para esta crise planetária são os países ricos, onde alguns governos e empresas já começaram a elaborar e implementar leis e medidas de forma a cumprir com os objectivos do acordo climático de Paris.

Este projecto de Dissertação de Mestrado foi realizado no Departamento de Produção da Decathlon Portugal na atividade industrial do Calçado, e teve como objetivos:

- Identificar situações ambientais graves no painel de fornecedores;
- Formular e testar soluções com rumo à sustentabilidade;
- Avaliar as vantagens e desafios.

Inicialmente, foi realizada uma avaliação ambiental que expôs as duas maiores fontes de impacto ambiental do painel de fornecedores: o consumo de energia elétrica e os resíduos descartados em aterro. Assim sendo, foi adoptada uma estratégia de transição energética para fontes renováveis em conjunto com duas iniciativas de economia circular com vista na redução e eliminação dos impactos ambientais relacionados com consumo de energia eléctrica e com os resíduos destinados para aterro.

A estratégia adotada de consumo de energia "mais limpa" foi dividida em três prioridades que consistiram na contratualização do consumo de energia elétrica 100% de fontes renováveis e a instalação de painéis fotovoltaicos, por parte dos fornecedores de calçado. De modo geral, o painel de fornecedores conseguiu uma redução de 40 toneladas nas emissões de CO_2e mensalmente, o que corresponde a uma queda de 15% do valor inicial.

As duas iniciativas de economia circular envolveram resíduos de couro e de PVC, que mostraram trazer, não apenas uma redução considerável em termos de impacto ambiental, mas também uma

significativa poupança a nível financeiro. Quando ocorrer a implementação do projeto que trata os resíduos de pele, dentro do melhor cenário, será possível evitar a emissão de 3,7 toneladas de CO2e e uma poupança de €22.000, anualmente. Do mesmo modo, no projeto que visa a reciclagem de PVC estima-se que se evitará a emissão anual de 92,7 toneladas de CO2e para a atmosfera e uma poupança de €149,000.

Acknowledgements

I would like to leave a recognition of gratitude towards the Decathlon Portugal Production Team for the opportunity, but especially to the Footwear Industrial Division team that was able to board an intern during the worst time of the COVID-19 pandemic in Portugal.

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Para todos os demais, família e amigos, não existe forma de mostrar agradecimento suficiente pela jornada sofrida e enriquecedora que foram estes 5 anos.

"Who is going to fight that? Who is going to lead in the direction? Well, I hope lots of people. But I am sure that among them will be the Humanists, because by their very name. They celebrate Humanity. They want Humanity to survive, and they recognize that if they do survive it will be by its own efforts. Never can we sit back and wait for miracles to save us. Miracles don't happen. Sweat happens. Effort happens. Thought happens."

Isaac Asimov

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Abbreviations

FG	Finished Good
DP	*Département de Production* (Production Department)
FID	Footwear Industrial Division
PT	Portugal
CO2	Carbon Dioxide
GHG	Greenhouse gas
CO2e	Carbon dioxide equivalent
N2O	Nitrous oxide
NDC	Nationally Determined Contribution
REC	Renewable Energy Certificate
GO	Guarantee of Origin
MWh	Megawatthour
kWh	Kilowatthour
kg	Kilogram
PVC	Polyvinyl chloride
PU	Polyurethane
EVA	Ethylene-vinyl acetate
PET	Polyethylene terephthalate
rPVC	Recycled Polyvinyl chloride
mm	Millimeters

Chapter 1

Introduction

Planet Earth is so far the only planet known to humanity that can support life as we know it. It is home to innumerable species and natural phenomena that have achieved a natural equilibrium of existence. Humankind has been learning that everything in nature is interconnected in some way or another, and that this equilibrium can be fragile when our species fails to acknowledge and act over its impacts in the ecosystem.

For centuries humans have improved their means to explore more each time the natural resources of this planet. Their capability to learn, adapt and overcome challenges is remarkable and it is what ultimately makes them the top species. But history does not lie when it shows that many civilizations have collapsed due to their irresponsibility towards the environment, specifically the matter of resource depletion, and also uncontrolled climate changes.

Currently, humanity faces several big issues related to the environment that have been originated by human activity. Ecosystems are changing drastically, species are going extinct, and humanity is also endangering itself in the middle of this. Global warming is the topic that worries the most scientists, as it presents high complexity and various ramifications of cascading effects.

Corporations and governments are starting to put efforts into achieving the goals of the most recent global climate agreement - the Paris Agreement. Limiting an increase in the average surface temperature of the Earth to well below 2 degrees post-industrial revolution, or preferably 1.5 degrees will be essential to ensure a relatively stable climate in the future.

This Master's Thesis work was conducted at Decathlon Portugal production department in the Footwear Industrial Division. The projects developed aimed to improve the environmental sustainability of Decathlon and its suppliers' activity.

This Chapter will introduce the company where this project was conducted, its environmental sustainability commitment, the main objectives of this project as well as its structure.

1.1 The Company - Decathlon

Decathlon is an international sports retail company founded by Michel Leclercq in 1976 in Englos, France, with a new concept of gathering all the sports inside the same store. Decathlon is currently the biggest sports retail company in the world with over 100,000 employees and 1647 stores in 57 countries from Europe to Asia, South and North America, and North Africa. The company sells a very wide range of sporting goods that go all the way from running shoes to surfboards to hunting and fishing products. Most of the items in the store are designed and developed by Decathlon's 85 brands such as *Quechua* (Hiking and Camping), *Nabaiji* (Swimming), *Tribord* (Sailing), *B'Twin* (Cycling), *Kipsta* (Team Sports), and more [1] [2].

The conception and design of new products from the 85 Decathlon brands are done in several R&D labs spread across France, mostly, where designers and product engineers work together. These sites are strategically located in specific areas where the surrounding ecosystem of companies, associations, nature, and sportspeople, allow for rich innovation and co-design. For example, *Tribord* Sailing Lab, the sailing brand, sits in La Rochelle, one of Europe's best-known sailing venues where *La Rochelle's Société des Régates Rochelaises* has been running major sailing events for over 150 years [3] [4].

The manufacturing of Decathlon's creations takes place within its industrial network spread across 47 countries, being Asian countries the ones with larger production volume. The production management is done locally by what it is called a DP (*Département de Production*) and some countries can have more than one DP depending on the dimension of the overall manufacturing project and geography. These DPs are internally divided into different industrial activities each concerning a product typology that is made in that country, and also include teams in charge of Logistics, Human Resources, and Finances (the example regarding DP Portugal will be given below). Each industrial activity is composed of a team of Production Leaders with distinct responsibilities, such as Quality, Supply, Industrialization, and Development. Every team is managed by a Production Team Manager. These teams are responsible for the operational management of their suppliers.

1.1.1 DP Portugal and FID PT

DP Portugal was created in 1992 with footwear production, a traditional industry in Northern Portugal. It is based in Maia-Porto, and it has diversified its core business since its start. Today, DP Portugal accounts for six industrial activities - Textile, Footwear, Metal, Bikes, Plastic, and Helmets - and works with more than 28 suppliers. Among the main products are sailing and horse riding shoes, plastic, and metal bottles, ping pong tables, basketball baskets, and all types of bicycles.

The Footwear Industrial Division Portugal (FID PT) is in charge of footwear manufacturing and will be the area of interest and action of this thesis work, therefore a brief presentation is necessary. FID sits as the third biggest revenue-generating activity in the DP Portugal, producing close to three million pairs of footwear yearly, managing 17 suppliers, located in Spain and Portugal. It is in charge of 13 different footwear typologies that make 89 different models and deals with a wide range of manufacturing processes.

Currently, FID PT is also responsible for a finished good (FG) supplier of waders (fishing suits), who is not involved in the manufacturing of footwear.

1.2 Decathlon's Environmental Sustainability Commitment

As partially explained in Section 1.1, Decathlon's activity goes way past the retailing of sporting goods. When it comes to environmental responsibility Decathlon is also accountable for what comes before the selling of the product and after it, including actions such as product transport, product manufacturing, product end of life, and even teammate and customers' travels. Figure 1.1 offers a clear quantitative understanding of this.

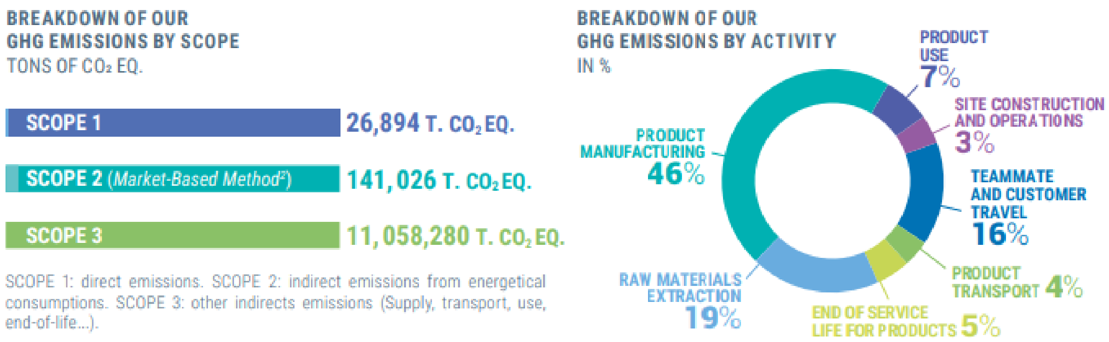


Figure 1.1: 2019 Decathlon greenshouse gas emissions (Source: Decathlon [2]).

In order to take action against climate change and to minimize overall greenhouse gas (GHG) emissions Decathlon started measuring its emissions and has committed to RE100 - a " global corporate renewable energy initiative bringing together hundreds of large and ambitious businesses committed to 100% renewable electricity" [5] - and to SBTi (Science Based Targets initiative) - that provides "companies with a clearly-defined path to reduce emissions in line with the Paris Agreement goals" [6].

Moreover, Decathlon has signed the European Commission Green Consumption Pledge [7] - an initiative that "calls upon businesses in various sectors of the economy to undertake concrete, public and verifiable commitments to reduce their overall carbon footprint, to produce and market more sustainable products and to redouble their efforts towards raising the awareness of consumers about the impact of their consumption choices" [8] - and it also signed the United Nations Fashion Industry Charter for Climate Action which has the "mission to drive the fashion industry to net-zero Greenhouse Gas emissions no later than 2050 in line with keeping global warming below 1.5 degrees" [9] [10].

All of these commitments are in line with Decathlon own 2020-2026 Transition Plan [11], where in the section "Preserving Nature" the following 2026 goals are presented:

- 75% reduction GHG in emissions from scope 1 and 2;
- 100% renewable electricity on the retailing and direct production sites;
- less than 1% of products shipped by air;
- 90% of the sold products are produced from suppliers autonomously managing their CO2e (Carbon dioxide equivalent) emissions;
- eliminating single-use plastics from the value chain;
- 100% of Decathlon products with environmental labeling;
- 100% of products eco-design.

1.3 Main Objetives

The project was developed in two different but interconnected areas of interest. The first one is relative to the monitoring of CO2e emissions and the empowerment of FID PT suppliers into making a shift to electricity consumption 100% from renewable sources, while taking into account what the Portuguese and Spanish energy markets offer, potential extra costs on the electricity bill, and most importantly the impact in the CO2e emissions.

The second area of action is about a preliminary testing of two circular economy concepts inside FID PT activity, including the assessment of initial technical challenges - such as ensuring the compliance with specific technical requirements, as well as the testing of different material compositions - and potential future supply chain and industrialization challenges.

One of the circular economy models concerns the incorporation of leather residues - originated from a production process of a specific footwear model - into a rubber matrix to produce the outsole of the same model. The other one looks into the recycling of thermoplastic residues from the production of waders (a type of fishing suit) to produce thermoplastic injected boots.

1.4 Project's Structure

This thesis is structured in six full chapters comprising two approchaes for a more sustainable Earth - circular economy and renewable energy. In Chapter II it will be given a general overview of the current Planetary Crisis, passing through the current civilization's dependency on fossil fuels to generate electric power. Then we will discuss worldwide greenhouse gas (GHG) emissions, the newest agreement to fight climate change signed by 197 nations, and a spotlight for the environmental impacts of landfills which will become important when considering the two circular economy projects. Regarding Environmental Sustainability, the circular economy concept will be presented together with the "green" energy and renewable energy certificates, and how to measure CO2e emissions. Finally, a Footwear Manufacturing moderate approach will consist of the manufacturing of leather footwear, rubber outsoles and thermoplastic injected footwear, including also the environmental concerns of such activities.

In Chapter III the supply panel and the relationships between suppliers and Decathlon will be presented. Then, it will be evaluated the environmental, energetic, and landfill waste situations of the suppliers. In the end, a brief introduction to the selected footwear models will be provided since it will be important to understand the circular economy initiatives.

In Chapter IV are exposed the proposed solutions for the energy and landfill waste identified issues as well as the expected results from each.

Chapter V expresses the results and respective discussions for the proposed solutions in Chapter IV.

Finally, in Chapter VI one can find the project's conclusions and suggested future work.

Chapter 2

Literature Review

In this Chapter, an overview of the current Planetary Crisis is given together with the actual dependency of fossil fuels to generate electricity, the global GHG emissions, the most recent global climate agreement, and an important look into the environmental impacts of landfills.

Then, it is presented a section about environmental sustainability where circular economy, "green" electricity, and renewable energy certificates will be discussed, plus it will be explained how the industry is measuring its own GHG emissions.

Finally, it will be exposed a moderate approach to the production of footwear, particularly leather footwear, rubber outsoles, and thermoplastic injected footwear. The end of life for leather and PVC - a well-known thermoplastic - materials will also be contemplated.

2.1 Planetary Crisis

"Global warming is humankind's most significant accomplishment to date, albeit a negative one"(Jeremy Rifkin in his book "Hydrogen Economy"). And indeed we have been able to alter the biochemistry of the Planet Earth in an unprecedented radical way for the sake of meeting our energy consumption demands that have allowed humans an increasing prosperous living since the 18th century - the start of the Industrial Revolution and the use of coal as fuel [12].

The increasing energy demand comes with a price. The current 21st-century climate crisis that our civilization faces is in a great manner due to the burning of fossil fuels - oil, natural gas, and coal - that release GHGs, namely CO2 and N2O. These gases accumulate in the atmosphere and intensify the naturally occurring greenhouse effect of Planet Earth in such a way that destabilize ecosystems and endanger life itself, including the human life.

The next decades and the commitment to limit the increase in the average planet's surface temperature to 1.5 degrees (post-industrial revolution) will be decisive to mitigate the risk of a potential planetary catastrophe and determinant in the way that future generations will judge our actions.

Besides this major topic about global warming, we also face several other environmental problems. Resource depletion and poor waste management, two products of an industrialization mentality that pursues mass production to reach low production costs with a unique focus on economic growth. As humanity struggles to maintain a balance between resource consumption and its renewability, it comes to find that the most essential natural resources are already under increasing pressure - by 2030 47% of the population will be living in areas of high water stress, forests are disappearing at an alarming rate, grassland degradation is about 20-35 percent, overfishing led to at least one-quarter of marine fish stocks to be overexploited or significantly depleted, and more [13]. The general lack of interest and investment into waste management in so many decades is now a global regret when humankind finds itself with severe issues such as marine plastic and microplastic pollution, open-air and closed landfills - that account for 19% of all methane emitted by human activity, plus contribute to soil, water, and air pollution - and illegal waste dumping and water discharges into water streams [14].

2.1.1 Fossil Fuel Dependency to generate Electric Power

The electrification of energy systems has allowed for a big transformation in the way we produce, transport and use energy, powering the shift from a biomass-dominated (mainly wood) energy system in the 18th century to a modern one highly dependent on fossil fuels - mostly natural gas and coal [15].

The International Energy Agency (IEA) presents in Figure 2.1 the global electricity generation mix data for the period 2010-2020.

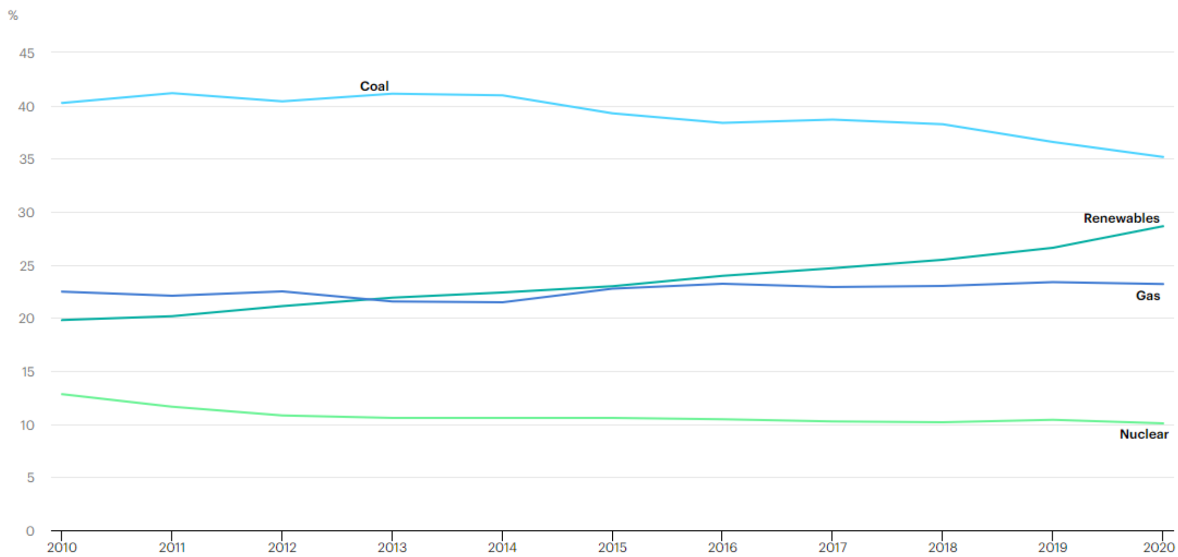


Figure 2.1: Global electricity generation mix (Source: International Energy Agency [16]).

As of 2020, coal accounted for 35% of worldwide electricity generation, natural gas 23%, renewable energy 29%, and nuclear power 10%. Despite an evident downward trend for coal and an upward one for renewables in past years, a staggering 58% falls into the fossil fuel domain remind us of how highly dependent developing and developed countries are on these energy sources [16].

It is well known that developing countries with little room to invest in the relatively new and arguably unreliable renewable energies, turn themselves to the more solid options - fossil fuels - to power their economic growth. The two fastest-growing developing nations in the world during the last two decades happen to be, not surprisingly, the biggest coal consuming countries in the world - China and India [17] - and do not seem to be slowing down on their consumption [18] but instead with a steady increase prevailing since the beginning of the 21st century [17]. In 2020, China relied on coal for 64% of its electric power generation [19], and India 69% [20].

The emerging economies from Southeast Asia concern the international community as the fast-growing populations will demand a higher energy consumption that will likely come, as it is right now, from the burning of fossil fuels - resulting in increased CO2 emissions [21].

The leaders in accelerating the transition to renewable energy sources are the European nations whose efforts yet seem to produce any significant change since many European countries are still heavily dependent on fossil fuels to meet their energetic needs, including the production of electric power. Most European countries (24 out of 29 analyzed in this study) count on fossil fuels to produce 60% of their energy, while the leading ones on this green transition - the United Kingdom and Germany - secure 80% of their energy demand through fossil fuels [22].

Finally and since this thesis project was conducted in Portugal the current scenario is shown in Figure 2.2.

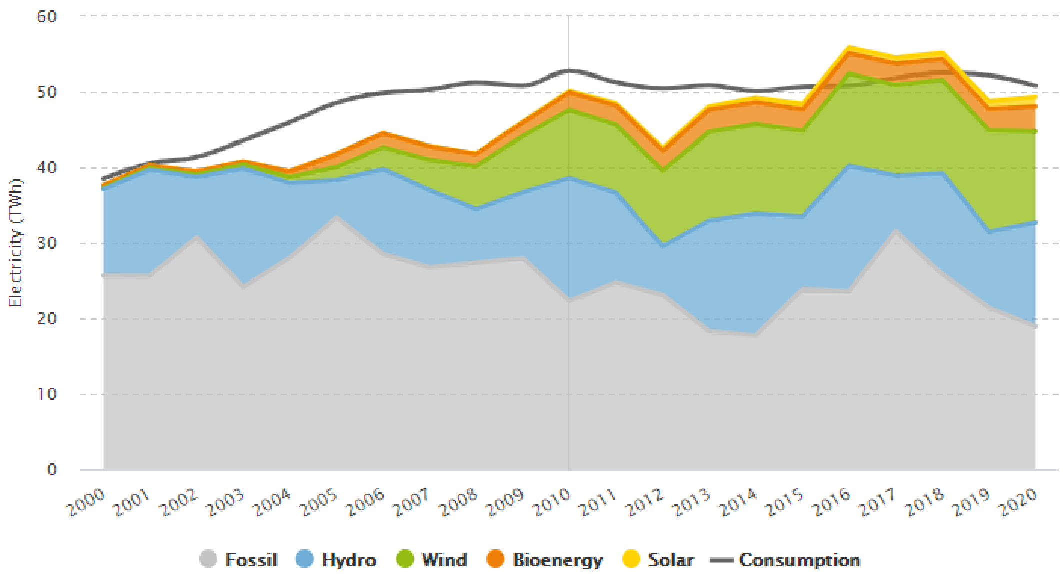


Figure 2.2: Portugal's electricity generation mix (Source: Portuguese Renewable Energy Association [23]).

In Portugal 2020, 38% of the electric power generation was due to fossil fuels, 28% to hydropower, 25% to wind power, 6,5% to biomass, and 2,5% to solar power. Renewables accounted for 62% of the total energy production which is quite impressive in comparison with other European countries. This is mainly because of the geographic location of the country and its natural resources that provide abundant renewable energy suitable for the production of electricity that can still gain more share in the upcoming years as the country aims for a decarbonization path [23].

2.1.2 World Wide GHG Emissions

The increasing levels of GHG in the atmosphere due to human activity are widely scientifically accepted as the major driver for climate change. The principal gases responsible for the naturally occurring greenhouse effect are CO2, CH4 and N2O, however since humans have powered the increase in the emissions of these gases - CO2 and N2O mainly from the combustion of fossil fuels [24], and CH4 mainly from agriculture, energy and waste sectors [25] - today:

- Carbon dioxide (CO2) is at a level **148%** greater than pre-industrial levels;
- Methane (CH4) is at a level **260%** greater than pre-industrial levels;
- Nitrous Dioxide (N2O) is at a level **123%** greater than pre-industrial levels [26].

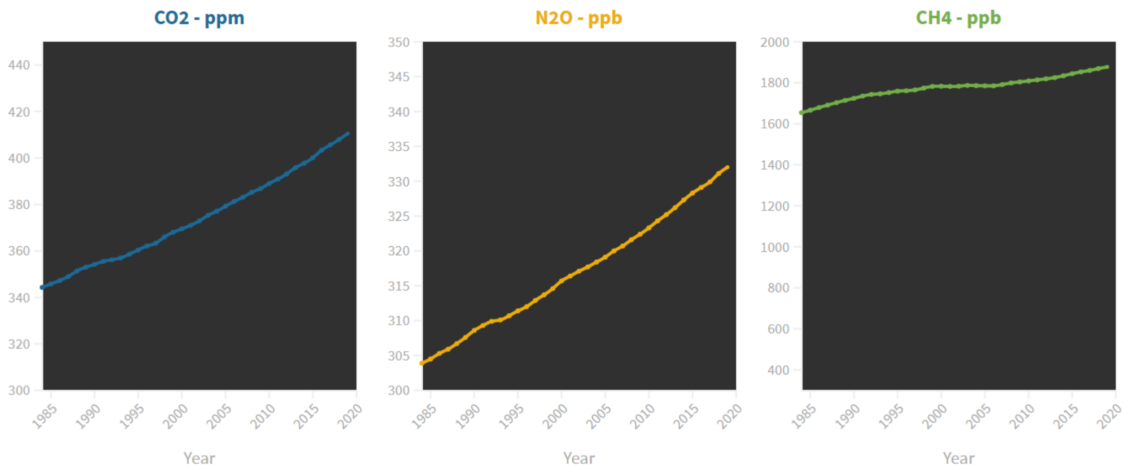


Figure 2.3: CO2, N2O and CH4 emissions history between 1985 and 2020 (Source: World Meteorological Organization [26]).

The main consequence comes in one form - a more potent greenhouse effect - that induces the rise of Earth's average surface temperature, the so famous phenomenon of Global Warming. In turn, the rise in temperature triggers countless events as in a chain reaction, like extreme weather events - cold and heatwaves, floods, droughts, wildfires, and storms - sea level rise (currently at 3.3mm per year), shrinking of glaciers, ocean acidification and innumerable other cascading phenomena that will affect ecosystems, wildlife and ultimately humans.

The most vulnerable people to climate and weather-related extreme events are migrants, refugees, and internally displaced people. During the period 2010-2019 an average of 23.1 million people per year were relocated due to weather-related hazards. Additionally, these ultimate occurrences compromise the growing of food in certain regions thus raising the concern about food security [26].

For a better understanding of the importance of the two main issues that this project concerns - landfill waste and electricity-related emissions - a general view of the global GHG emissions by sector is presented in Figure 2.4.

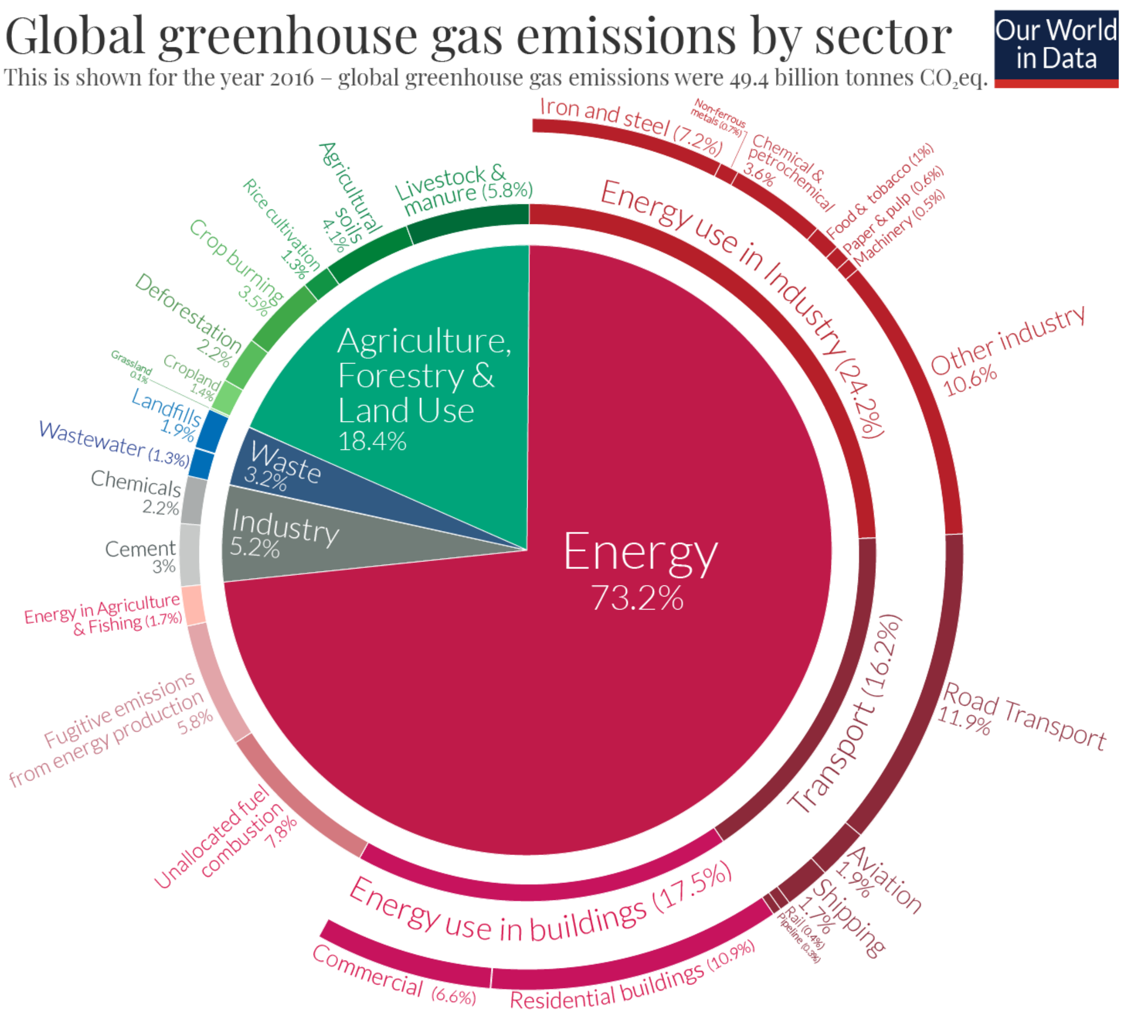


Figure 2.4: Global GHG emissions by sector due to human activity (Source: Our World in Data [27]).

The use of energy in the industry accounts for a considerable 24.2% of the total GHG emissions, which includes the consumption of electricity. And landfills take their cut of 1.9% from the total.

2.1.3 The 2015 Paris Agreement

Contrarily to the failed 1997 Kyoto Protocol, the 2015 Paris Agreement includes both developed and developing countries because the climate emergency is a globally spread matter shared by every nation within this planet [28] [29]. "The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016"(United Nations for Climate Change). It aims for a single goal of limiting global warming to well below 2 degrees and encourages ambitious efforts to keep it at 1.5 degrees, compared to pre-industrial revolution temperature levels.

The agreement works in cycles of 5 years with increasing climate action at every new cycle. In 2020, each participating country issued the nationally determined contributions (NDCs), which are the actions proposed by the country for the next 5 years that will allow for a complying decarbonization trajectory with the United Nations Framework Convention on Climate Change and respecting the Paris agreement goals. After 5 years of action, in 2025, the nations must enhance their NDC's to keep on track with the commitment, and the cycle repeats.

Considering that the Paris Agreement includes a great number of countries that might not have the proper means to power this transition by themselves, there is a framework laid out for financial, technical, and capacity-building support. In terms of finances, the agreement mentions the need for developed countries to financially help the less economically developed ones. This assistant will help mitigate emissions and in the adaptation and resilience against the adverse effects that climate change imposes. Regarding technology, it proposes that a mechanism is created through policy that can ease the development and transfer of technologies that can help with the reduction of GHG emissions and with the adaption to climate change. Finally, the Paris Agreement emphasizes the responsibility that developed nations have in respect of contributing with the proper knowledge and skill transfer onto the developing countries.

In order to keep track of the progress in a transparent way countries will report actions taken and progress in climate change mitigation, adaptation measures and support provided or received [30].

2.1.4 Environmental Impact of landfills

The growth of the global population and the non-stop increasing lifestyles demand constant increases in worldwide industrial production, thus generating more and more industrial waste. In the 1990s, the annual volume of waste production ranged between 300–800 kg per capita in developed countries and less than 200 kg per capita in other countries, and it is expected to see these numbers doubling in 2025.

Waste landfilling remains the most simple, adjustable, and economically advantageous manner of final disposal of solid residues. Landfilling is defined as the disposal, compression, and embankment fill of waste at appropriate sites as an effective way of managing materials that currently have no better alternative end of life - basically, everything that cannot yet be recycled and does not get incinerated or composted. The most popular type in many countries is sanitary landfilling, also called open-dumping, because of the relatively low cost and low technical requirements.

The major environmental impacts of landfills are GHG emissions (biogas) and leachates. The anaerobic (without oxygen) decomposition of organic matter leads to the production of CH4 and CO2 gases that usually end released into the atmosphere, though some landfills can capture the biogas to produce electricity [31]. Leachates are usually caused by rainfall or by infiltration of underground water through the insulating coat that contains the waste and avoids it contacting the ground. The water goes through the deposited waste and binds to dissolved and non-dissolved constituents through several physical and chemical reactions. Leachates are composed mainly of nutrients (like nitrogen), volatile organic compounds, heavy metals, and toxic organic compounds, making these liquids hazardous and toxic to human health and the environment - this one especially when leachates infiltrate in the ground and pollute soils and aquifers, driving up the risk of phenomena like eutrophication and bioaccumulation [32] [33].

2.2 Environmental Sustainability

In efforts to establish a sustainable way of development for humankind, it is important that certain aspects, that have been ignored for decades, start to gain relevance in the industry. The means by which we select, extract and transform natural resources need to be rethought in a manner that begins taking into consideration all the aspects and correspondent environmental impacts of the production chain. Here, supply chains become important due to their wide spectrum nature that allows for a global view of the activities and parties involved in making a product, therefore aiding in identifying the different sources of environmental footprint and facilitating the construction of solutions.

Following this line of thought, three important concepts are presented next.

2.2.1 Circular Economy

The linear production concept has been the model of expansion of the global economy since the industrial revolution. Natural resources are extracted and processed to produce goods and services, and then are scrapped. For what concerns the economical growth it has been a marvelous ride, but the model deeply fails to consider the induced pressure upon the environment and the costs of handling, scrapping, and disposing of used materials, especially the hazardous ones.

As the global population targets 9 billion by the year 2050, the demand for products and services is expected to rise as well, and the current model becomes no longer a viable one. Therefore, to achieve the United Nations Sustainable Development goal 12 [34], on responsible consumption and production, a transformation on how our economy operates needs to occur - the shift to a circular economy model is urgent.

A circular economy means that the economic system works on the basis of reducing waste as much as possible. Incentives are provided to reuse materials instead of disposing of them and extracting new ones, in this way resources are used in a much wiser manner saving them for the future. In this circular production model, all forms of materials return to the dynamic economy being reborn into new things. The manufacturing processes are energy-intensive, require time, capital, and resources that in turn have to be extracted, requiring energy, and so on. These assets can be spared if reincorporation takes place, reducing related emissions and diminishing waste in landfills.

For example, organic waste could be transformed into high-value protein through the production of insect larvae. The electronic waste recycling industry has the potential of €55 billion annually.

It is estimated that the potential global economic gains from this circular model are €1 trillion per year globally in material cost savings [35] [36].

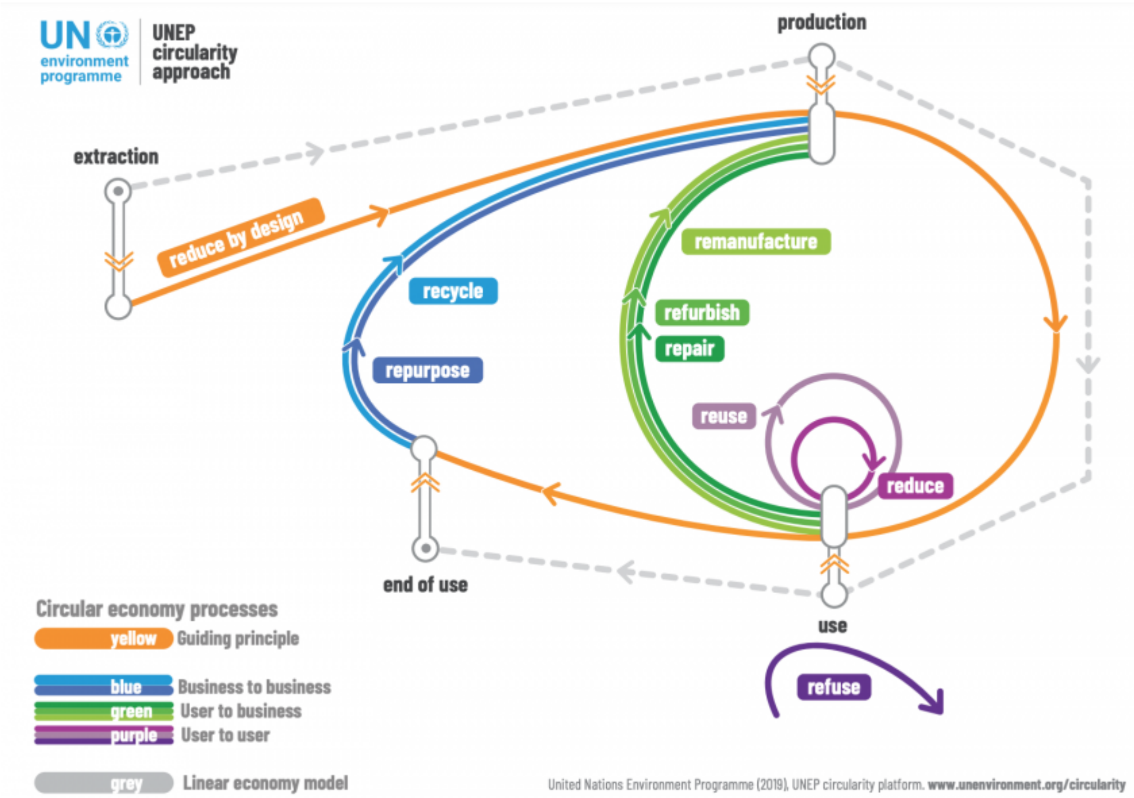


Figure 2.5: Circular Economy Concept (Source: United Nations [36]).

2.2.2 "Green" Electricity and Renewable Energy certificates

Since the beginning of the 21st century, environmental awareness has been gaining traction and slowly policies have been put into action to allow for a faster energetic transition from fossil fuels to renewable energies. In recent years "green" electricity contracts have appeared worldwide. These electricity contracts, for domestic and industrial uses, guarantee to the consumer that the consumption of electricity is generated 100% from renewable sources - like solar, hydro, wind, biomass, etc... At first, it may sound incredible, but a deeper reflection reveals that it is not that simple, never is.

Electricity is an abstract concept, one can only try to imagine it flowing through electric lines and reaching cities and houses to be consumed. Besides being a complex electromagnetic phenomenon it is instantaneous, i.e. the amount produced must be consumed in the instant. The sun, the wind, and the water streams are not constant energy sources. They depend on many variables and predicting them is a difficult task with high margins of error. The sun does not shine at night, the wind does not blow every time and rivers do not have the same flow throughout the year. Adding to this, electricity demand is not constant either but can be better predicted. Therefore two opposite scenarios happen in every national electric system:

1. The electric production from renewables is higher than the current demand in the area, and since energy storage systems are not still part of most electric systems, the surplus energy can be exported or curtailment is necessary to reduce the power input and safeguard the grid infrastructure. - an example of curtailment is shifting the wind turbine blades' angle of attack to a lower degree [37].

2. Or the electric production from renewables is lower than the current market's demand in the area, and in this case coal and natural gas power plants will have to produce the remaining to balance the system [38].

With this said, it is quite clear that companies commercializing electricity would have a hard time ensuring customers a 100% consumption of renewable electricity, constantly. The only reason that allows such a claim is because of renewable energy certificates (RECs) [39], also called Guarantees of Origin (GOs) in Europe [40].

A REC/GO is issued every time a renewable energy farm produces a MWh of electricity and injects it into the grid. The certificate can then be sold to the highest bidder, and in turn, the buyer (energy company) can claim the electricity they are selling is coming from renewable sources in quantities according to the certificate. However, here's when the situation gets tricky: the certificates are traded together with the purchase of renewable electricity from the energy farm, but they can also be bought separately. Therefore, an extreme case of "Greenwashing" would be an energy company commercializing electricity from non-renewable sources, but at the same time claiming the opposite while backing it up with these certificates. Additionally, the system is blind to regions and time. Regarding space, it is possible to buy certificates from other countries and regions without grid connection to the place where the electricity is consumed. Regarding time, one can also buy RECs for energy that has already been produced and consumed [41].

Nevertheless, the goal of the REC/GO systems is to make it possible for the consumer to signal to the energy market his demand for more renewable energy. The certificates act as mean of directing financial investment to the renewable energy farms.

2.2.3 Measurement of CO2e Emissions in the Industry

In order to quantify all the global warming inducing gases that are released, it is commonly used CO2e as the unit that expresses the amount of CO2 which would have the equivalent global warming effect.

Today there are several companies offering platforms that indirectly calculate CO2e emissions. The principle is simple, the platform requires data from different categories related to the industrial activity - like electricity, water, diesel, etc... - and then using emission factors from trustworthy databases it calculates CO2e emissions. Examples of such databases are the United Nations Intergovernmental Panel for Climate Change emission factor database [42] and the *Base Carbone* from the French Ecological Transition Agency [43].

Assessing correctly CO2e emissions of a company is a complex process because no company works individually making it difficult to set a limit to the extent of its footprint. For example, a supplier that ships a component to a factory should be responsible for the transport-related emissions rather than the factory? Or the shipping company is the one responsible? Attributing responsibility and setting limits can be difficult and lead to errors. That is why it is important to establish some common ground such as the definition of emission scopes:

- **Scope 1 (Direct emissions)**: accounts for direct emissions released onsite. For instance, combustion of fuels in furnaces and vehicles, and emissions from chemical production.
- **Scope 2 (Energy indirect)**: associated with the consumption of purchased electricity, heat, steam, and cooling. Emissions are not released onsite but on the sources not controlled or owned by the organization.
- **Scope 3 (Other indirect)**: all other emissions as a consequence of the organization's actions. For example, recycling, water treatment, not owned logistic transports, and others [44].

The monitoring of these scopes enables better understanding of the organization's environmental impact and a better decision-making process on which areas are more urgent to act upon.

A simple example would be:

- A Portuguese company consumed 100,000 kWh of electricity in January 2020. The database *Base Carbone* (version 11.5) predicts a factor of 0.255 kgCO2e/kWh for the electricity consumption in Portugal. Therefore the company is accountable for the emission of 25,500 kg of CO2e to the atmosphere during that month.

2.3 Footwear Manufacturing

Since this project concerns the Portuguese footwear industry it is important to do a simple overview of the industry, some selected processes and materials, and their respective environmental impacts.

The general footwear sector utilizes a large variety of raw materials, being the most common textiles, plastics, rubber, and leather. The products range from regular and sporting footwear to more specialized ones, such as protective footwear.

This range of products reflects the many industrial processes required: cutting of textiles, leather, and plastics, stitching of pieces to assemble the upper part of a shoe, cementing of the upper part to the insole and outsole, injection of polymers such as PVC (Polyvinyl chloride) to make boots or outsoles, and PU(Polyurethane)/EVA(Ethylene-vinyl acetate) to make lightweight and soft outsoles, and rubber vulcanization to produce rubber outsoles [45].

2.3.1 Production of Leather Footwear

The general manufacturing process of leather footwear in factories starts with the leather itself. The material passes through the first phase of quality control, where defects are identified and marked by highly experienced workers. Then, the nesting phase, where an optic scan calculates the total area of leather while considering the signaled defects, and arranges a puzzle of different pieces needed to be extracted in a way to maximize the cutting. Finally, the cut of the displayed pieces required to make the shoe is done by a vibrating knife or a punching tool [46].

The next steps will differ for each type of construction. For what concerns this project a brief description of the "Mocassin" construction type is relevant.

After the leather cutting, the leather pieces pass through the sewing process resulting in a leather upper. The leather upper is similar to a "bag" that goes all around and closes on the bottom. It is then stitched to the insole that provides the early foundation of the shoe - completing the upper part of the shoe. The midsole, if present, is cemented (usually by applying glue) to the outsole, and then the upper part is cemented to the midsole [47] [48]. Figure 2.6 illustrates the different parts of a leather shoe.

Although this description is true for many, there are always variations to the process.

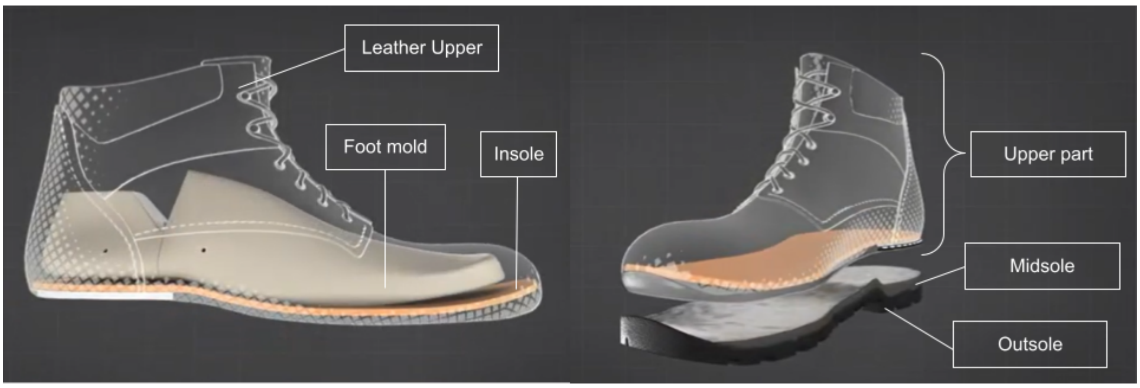


Figure 2.6: Main parts of a leather shoe (Source: Adapted from [49]).

2.3.1.1 Leather Material

Leather has been a desired material for footwear since ancient times. It is a material that with the right treatment can offer excellent abrasion resistance and waterproof properties while maintaining great attributes of a natural product like good breathing and being malleable without tearing.

The leather used to produce regular footwear comes as a sub-product of the meat industry, usually from bovine animals. Nonetheless, some hidden parts of a shoe can contain other types - like swine leather - because of its lower cost and specific characteristics.

The production of leather includes an important process called tanning, which is where naturally biodegradable animal skin is transformed into a physically and chemically stable material. There are several different tanning methods, but the most common is chrome tanning. It involves a bath using chromium(III) sulfate to guarantee to the leather its stability by means of chemically bonding chromium to the leather fibers' surface. Chromium is a highly toxic element for microorganisms [50] and its presence on fibers makes the leather resistant to putrefaction. Furthermore, the chrome tanning confers good softness, high thermal and water stability, and it is considered a fast tanning process as it only takes a few days [51].

2.3.1.2 Leather End of Life and Environmental Impact

At first, one could think that the use of leather reflects a sustainable approach to a product that otherwise would be discarded. However, it is very much the opposite.

The chrome tanning industry is highly resource-consuming and very pollutant. Only 20% of the hide makes its way to finished tanned leather and 60% of the chromium used is discarded in solid and liquid waste. 1000kg of hide generate 50,000 liters of wastewater (containing 5kg of Chromium) and only 200Kg of finished tanned leather. The discharge of wastewater rich in chromium, besides representing a loss of resources, carries a big environmental weight. The treatment systems for these waters generate chrome-containing sludge - a categorized hazardous waste difficult to deal with [52].

Furthermore, during the production of leather goods - including footwear - part of the material ends up as waste as a result of the cutting process. Although the cutting is already optimized, each hide is different in shape, thickness, and in defects presence, which forces 15-20% of the leather material to be disposed of as scraps.

The end of life of leather from tanneries, footwear factories, and users is usually landfilling or incineration. In landfills, despite the contribution to the environmental impacts already stated in 2.1.4, there is a particularly dangerous aspect of chrome tanned leather.

Chromium(III) compounds are present in the finished leather as a result of the tanning process. Chromium(III), the trivalent state (+3), is the most stable oxidation state of chromium and plays an important role in glucose, lipid, and protein metabolism, plus is not toxic in moderate amounts. In a landfill, when it rains, chromium(III) can leach and reach sources of drinking water. During the water sterilization process, chromium(III) oxidizes into chromium(VI) - the hexavalent oxidation state - and reacts with magnesium and calcium ions occurring in drinking water to produce magnesium and calcium chromate or dichromate salts. Such compounds are proven to be carcinogenic [53].

Leather waste that is incinerated allows for energy capture to produce electricity. However, the combustion reaction leads to the oxidation of chromium(III) into chromium(VI) producing airborne particles that cause lung cancer as well as lung toxicity, and highly hazardous ashes that require proper disposal [54] [55].

Combining these issues with the fact that tanned leather is a long-lasting non-biodegradable material, it is evident the actual risk for humans and the environment.

2.3.2 Production of Rubber outsoles

Rubber is a preferred material for outsoles thanks to its great impact absorption, extreme elasticity, abrasion resistance, traction, waterproofing, and low cost.

Natural rubber is chemically known as polyisoprene and is extracted from the tree *Hevea braziliensis*. Modern rubber manufacturers often use a mixture of natural rubber and synthetic ones to get desired characteristics on the final product.

The rubber production starts with raw rubber which is initially not very strong, does not maintain its shape after a large deformation, and can be very sticky. The process by which the rubber gains its properties is called vulcanization. Vulcanization creates a network of cross-linked rubber macromolecules and is achieved thanks to high temperatures and the introduction of cross-linking agents such as sulfur and peroxides. The final result is a material that retracts to its approximately original shape after a rather large mechanically imposed deformation.

Producers of rubber outsoles use aluminum or stainless steel molds where pieces of prepared rubber are put into. Then using high temperature and pressure (hydraulic presses) the rubber melts to meet the mold's shape and is subjected to a vulcanization time during which the cross-linking phenomenon takes place [56] [57].

2.3.3 Production of Thermoplastic injected footwear

Thermoplastics are plastic polymers that become softer as the temperature rises until the melting point where they start to melt into a liquid. If the temperature decreases the material takes again a solid state. Heating and cooling cycles are possible without the material risking losing its chemical and mechanical properties.

Such characteristics make thermoplastics ideal to produce fully injected footwear and add the advantage of being easily recyclable - waste can be shredded to pellet size and injected again. Manufacturers use injection molding machines to produce injected footwear. The working principle is quite simple: pellets of thermoplastic are inserted into a heating chamber, where there is a moving screw inside that pushes the material forward while it goes past the melting point. At the end tip of the chamber, there is a mold where the thermoplastic is injected. It is possible to produce injected footwear with different colors and materials, as some machines have more than one heating chamber and more injection points in the mold [58].

2.3.3.1 PVC End of Life and Environmental Impact

PVC is a commonly used thermoplastic in various applications, including boots. In 2019, PVC accounted for 10% of the European plastics demand [59].

There is a distinction between flexible and rigid PVCs. The flexible ones have an addictive know as plasticizer that confers them the characteristic. The most used plasticizers are standard phthalates, which represent 85% of the global production of plasticizers. These compounds are heavily regulated by European Union due to their toxicity to human health, namely to reproduction and fertility.

PVC products have a usual end of life assigned - landfilling. Despite its great recyclability characteristic, PVC waste can be in conditions (degraded or bonded to other materials) that do not attract interest to it, or simply there might not be any proper recycling facility to transform it.

In the landfill, literature states that vinyl chloride - a highly toxic gas - is not originated from PVC, but rather from other sources. The release of heavy metals is also insignificant compared with other materials, but should not be neglected. Phthalates are not released by leachate action but are slowly decomposed in aerobic conditions, remaining in the PVC for a long time. Additionally, there is no degradation of the PVC polymer in a landfill, which is not surprising considering that the containing layer for leachate in a landfill is usually made of PVC.

Overall, the literature concludes that PVC products disposed of in landfills are quite inert and do not constitute a substantial impact on leachate or gas toxicity. Therefore, admitting it to be an acceptable intermediate disposal option. Nonetheless, there are still environmental impacts associated with the transport, landfill management, and production of unnecessary new PVC. Plus, it is a waste of a resource derived from a non-renewable source - oil [60] [61] [62] [63].

Chapter 3

Description of the Initial Situation

In this Chapter will be exposed the initial situation of the supply panel in terms of who the suppliers are and the relationships between them and Decathlon. It will be conducted an initial environmental assessment on the supply panel to identify the most concerning sources of environmental impact and then, the two biggest sources will be discussed in detail. Finally, relevant footwear models produced by the supply panel will be introduced since they will integrate the circular economy solutions ahead.

The timeline of this project started in September 2020 and lasted until June 2021. This will only be relevant for the initial energetic assessment, the proposed solution and results regarding this topic.

3.1 FID PT Suppliers Presentation and Relationships

A brief introduction to the involved FID PT suppliers is necessary to better understand the work done and its results. In Table 3.1 a designation is assigned to each supplier, together with the categorization of the relationship with FID PT (finished good or component supplier) and the end product of their activity.

Supplier Name	L1	L2	T	R	C	W	X1	X2
Type	FG	FG	FG	Component	Component	FG	Component	FG
End product	Leather footwear	Leather footwear	Thermoplastic injected footwear	Rubber outsoles	Thermoplastic compound	Waders	Leather	Footwear

Table 3.1: FID PT Suppliers.

Suppliers L1 and L2 are leather footwear manufacturers and have a direct relationship with FID PT to whom they sell finished goods. R is a rubber outsoles producer and X1 is a leather tannery. Both are component suppliers of L1 and L2, for rubber outsoles and leather respectively.

Supplier C is a thermoplastic compounder that supplies T, the thermoplastic injected footwear manufacturer. In turn, T is a finished good supplier for FID PT.

W is a producer of waders (fishing suits) and X2 is a producer of footwear. Both sell finished goods to FID PT.

These relationships are illustrated in Figure 3.1.

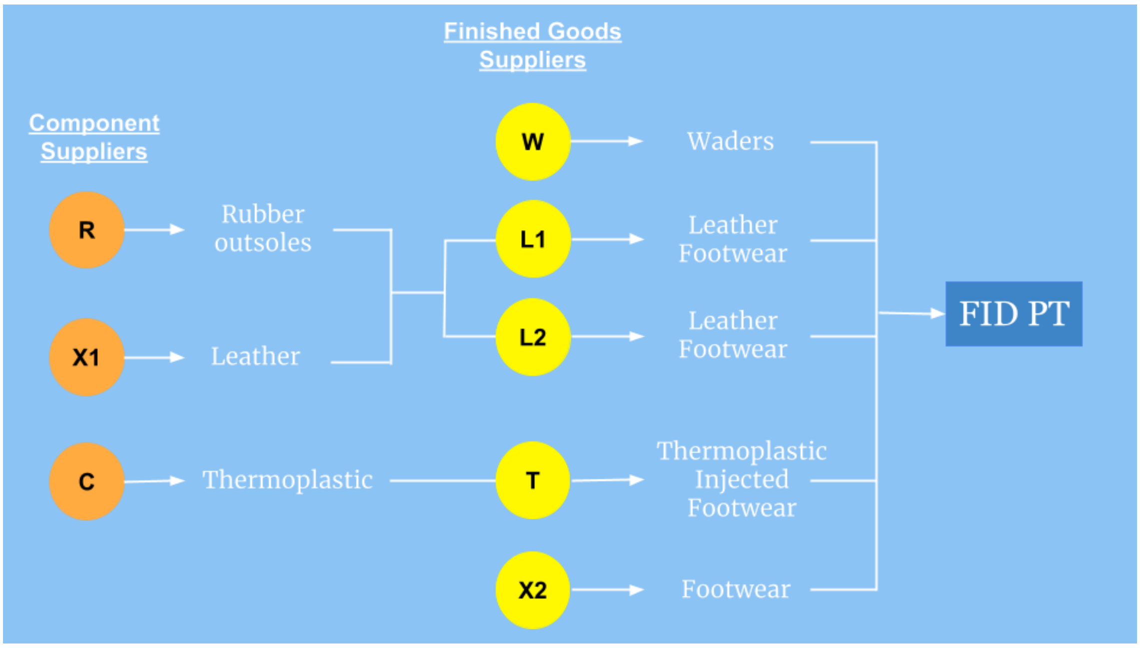


Figure 3.1: FID PT Suppliers Relationships.

3.2 Initial Environmental Assessment

In order to start reflecting on the best strategies to significantly reduce the environmental impact of the selected eight FID PT suppliers, it was essential to have a general picture of each supplier's footprint. Therefore, a CO2e monitoring platform with the same working mechanics as mentioned in subsection 2.2.3 was adopted by each one of them. The data collected through the platform provided an important view of the supply panel's emissions and facilitated the identification of common CO2e emission sources as well as the most significant ones.

From here further, it is important to keep in mind that the analysis of emissions was supported by a platform still in development. The platform is called "Resource Advisor" developed by Schneider Electric.

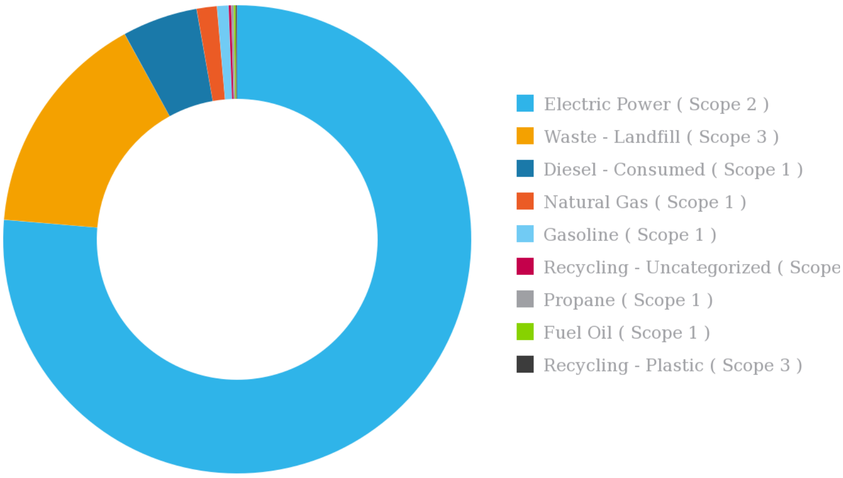


Figure 3.2: FID PT Suppliers CO2e Emissions per category.

Figure 3.2 presents the overall CO2e emissions of the FID PT suppliers. The three biggest CO2e emitting sources are the following:

- Consumption of Electric Power (scope 2) - **76.3%**
- Landfill Waste (scope 3) - **15.7%**
- Consumption of Diesel (scope 1) - **5.2%**

Every supplier's factory utilizes energy in the form of electricity to run almost every machine. Considering that the production of electricity in Portugal is still dependent on fossil fuels as seen in Figure 2.2, and that the factories consume large amounts of it, it is expected a weighty share of emissions from this source. This is a common aspect to almost every supplier - electricity consumption is the number one contributor to CO2e emissions.

Waste generated that ends up in a landfill is also a serious issue in this supply panel. Most of this waste includes tanned leather, textiles, flexible PVC, and other residues.

Finally, the consumption of diesel to power the truck and car fleets is also a big source of CO2e emissions.

3.3 Initial Energetic Assessment

As shown in Figure 3.2, the consumption of electricity carries the major environmental impact of the supply panel in terms of CO2e emissions. So, a detailed view of the supply panel's energetic situation was helpful to formulate solutions.

It is important to emphasize that the CO2e monitoring platform used considered zero emissions related to the consumption of electricity from "green" energy contracts - the ones that secure electricity from 100% renewable sources - and from onsite renewable electricity production and self-consumption.

At the beginning of this project (September 2020), only suppliers L2, X1, and X2 had a "green" energy contract. Suppliers L1, C and W already owned solar photovoltaic panels in their factories that produced a percentage of the consumed electricity, therefore helped partially reduce electricity consumption-related emissions.

All other suppliers did not have any solar panels nor a "green" energy contract.

Current monthly electricity-related CO2e emissions were considered for each supplier as a starting point. For the suppliers with "green" energy contracts, the monthly emissions were considered nonexistent. Therefore, suppliers L2, X1, and X2 had monthly CO2e emissions related to the electric power consumption of zero. For the suppliers without "green" energy contracts it was considered the monthly average of the period between September 2019 and August 2020. The CO2e values in metric tons were 6.4 for supplier L1, 33.4 for supplier T, 11.3 for supplier R, 316 for supplier C, and 6 for supplier W. Making a total of 373.1 metric tons of CO2e emissions emitted by the entire supply panel, monthly.

The initial situation is presented in Table 3.2, where the "check" mark indicates a positive scenario and the "X" mark a negative one.

Supplier Name	L1	L2	T	R	C	W	X1	X2	
Solar Panels	✓	X	X	X	✓	✓	X	X	
"Green" energy contract	X	✓	X	X	X	X	✓	✓	
Monthly electricity related CO2e emissions (metric tons)	6.4	0	33.4	11.3	316	6	0	0	373.1

Table 3.2: FID PT Suppliers Initial Energetic Situation and 2019 related CO2e emissions.

3.4 Initial Landfill Waste Assessment

This project also concerns the reincorporation of leather and PVC residues into new products, while avoiding disposing of them in landfills - which is the regular practice. With this said, the focus of this work was on incorporating these materials back into the production chain.

At the time, the CO2e monitoring platform was not able to discriminate distinct residues sent to landfill. It attributed similar impacts to materials like leather and PVC, even though as reviewed in the subsubsection 2.3.3.1 of the Literature Review, PVC is an insignificant contributor to landfill emissions and leachates. In any way, the platform only had the category "Waste - Landfill" - as seen in the Figure 3.2 - for every waste destined to landfill, and this was how the environmental assessment was conducted.

The development of this project might seem controversial due to the apparent insignificant impact of the PVC residue in landfill, however it is justified as a mean towards environmental sustainability. This is because it is relevant to note that the existing literature is based on laboratory models that might not come close to reality, and that there are other associated environmental impacts as explained in the subsubsection 2.3.3.1.

Tanned leather waste is produced by suppliers L1 and L2 as scraps from the leather cutting process, and by supplier X1 as a result of the production of finished tanned leather. Suppliers L1 and L2 produce big scraps of dyed tanned leather while supplier X1 produces undyed tanned leather fibers.

Suppliers L1 and L2 produce together 27 metric tons of leather waste yearly, thus being responsible for the emission of 31.3 metric tons of CO2e. In the same period of time, supplier X1 creates 344 metric tons that account for the emission of 398 metric tons of CO2e. Figure 3.3 illustrates these residues.

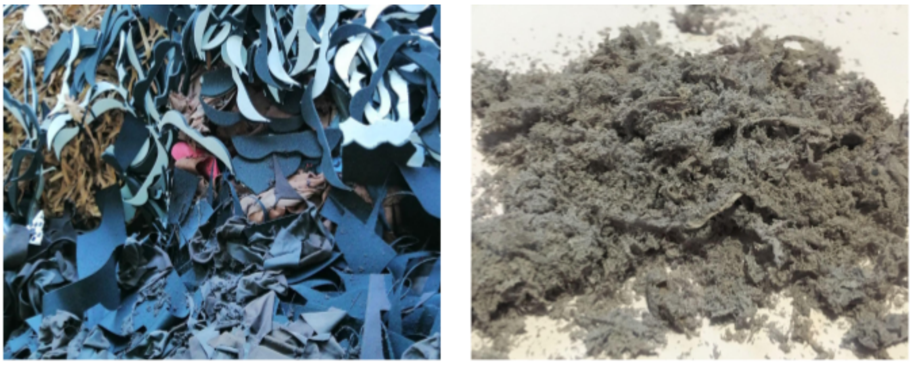


Figure 3.3: Suppliers L1 and L2 leather waste (left) and supplier X1 leather waste (right).

Switching to PVC residues, supplier W works with a material composed of two different layers bonded together, the first layer is a flexible PVC and the second Polyethylene terephthalate (PET). PVC accounts for 91% of the material weight and the remaining 9% is attributed to PET.

Yearly the supplier produces 80 metric tons of waste from this material as scraps from a cutting process, which makes him responsible for the emission of 92.7 metric tons of CO2e. The residues can contain a green or black PVC layer. The PVCs are chemically the same except for the pigment. The PET layer is white-colored.

Figure 3.4 shows what the residues look like.

Captions: 1 - PET layer (9% of the material weight); 2 - PVC layer (91% of the material weight).

Figure 3.4: Supplier W PVC waste.

3.5 Relevant footwear models

To better understand the proposed solutions in the next Chapter, it becomes essential to introduce the footwear models that will be considered.

Supplier T produces a variety of footwear models for FID PT, including PVC boot models A and B. Both boots are made of different PVC families, and none of them uses phthalates as plasticizers. Another common aspect is that boot A and B are composed of two parts: upper part and outsole, as can be seen in Figure 3.5, both parts are made with similar PVCs, but the outsole requires a harder and more abrasion resistant one. Additionally, because the PVCs are so identical the chemical bond between the outsole and upper part is achieved successfully.

These two parts mean that the injection process of the boot is done in two phases. In phase one, the outsole is injected with the proper PVC and in phase two the upper part of the boot is injected with a slightly more distinct PVC. The injection molding machine has two different heating chambers to melt each type of PVC.

The technical specifications for boot models A and B can be found in Appendix A.

The upper part accounts for 73% of the weight of boot A, while on boot B is 83%. Regarding annual production, the upper part of boot A requires 164 metric tons of PVC, while boot B only consumes 67 metric tons of PVC.

Supplier L1 produces a leather shoe model composed of a leather upper part, a midsole, and a rubber outsole made by supplier R. The annual production of this model requires 32 metric tons of rubber outsoles. The outsole technical specifications can be found in Appendix A. Figure 3.6 shows the shoe model.

Figure 3.5: PVC boot models A (left) and B (right) produced by supplier T.

Figure 3.6: Leather shoe model produced by supplier L1.

Chapter 4

Proposed Solutions

Taking into account the issues revealed in Chapter 3, this Chapter concerns the proposal of solutions for the electricity consumption, leather waste, and PVC waste related environmental impacts, while also expressing what would be the expected results.

4.1 Energetic transition

Decathlon's 2026 goal regarding renewable energy is to have all FG suppliers and retail sites consuming electricity 100% produced from renewable sources. Aligned with this, FID International aimed for the same goal but with a more ambitious deadline - the end of the year 2020. The local FID PT team agreed on chasing this objective for its own supply panel.

To achieve such a scenario it was proposed that the first priority would be to have each FID PT FG supplier settled with a "green" energy contract by the end of 2020. This would require presenting the concept to the FG suppliers, explaining the environmental and image branding benefits, convincing them to search the energy market for companies that offered this type of contract, and finally, if necessary, compensate for the price increase of the electricity. This dialogue would be needed for suppliers L1, T, and W.

The second proposed priority was the same as the first one but applied to the component suppliers R and C and with the deadline extended until the end of 2021. Even though it is not directly expressed in Decathlon's overall goal of 100% renewable electricity, component suppliers are part of the supply panel and therefore have a direct impact on the overall CO2e emissions that Decathlon wants to reduce by 75% in 2026, as stated in Section 1.2.

The third proposed priority was to encourage FID PT FG suppliers already with "green" energy contracts and without any solar panels, to start evaluating the potential installation of solar panels for onsite renewable energy production for self-consumption, and guarantee a solar panel installation by the end of 2021, without any defined minimum value for the production capacity. This targeted suppliers L2, T, and X2.

This third proposal might seem redundant because the suppliers would already be consuming 100% renewable electricity, but one must recall that, as reviewed in the subsection 2.2.2, "green" energy contracts do not provide exactly 100% renewable electricity because there is always RECs (renewable energy certificates) involved. Therefore, this final priority would reduce the dependency on RECs and increase the overall consumption of renewable energy by the supplier, besides enabling a reduction on electricity costs.

A summary of the three proposed solutions in descendant priority is:

- **Priority 1:** Ensure suppliers L1, T and W have a "green" energy contract by the end of 2020.

- **Priority 2:** Ensure suppliers R and C have a "green" energy contract by the end of 2021.

- **Priority 3:** Encourage suppliers L2, T and X2 to start evaluating the installation of solar panels onsite and guarantee an installation of any size by the end of 2021.

4.1.1 Expected results

First of all, it is important to highlight that priorities one and two are much easier to accomplish than priority three, considering that this last one requires a significant financial investment and that the year 2020 was not going very well for most manufacturers worldwide due to the COVID-19 pandemic.

Nonetheless, with the proposed priorities defined, the expected results were that priority number one would be fulfilled completely, this meaning that every FID PT FG supplier adopts a "green" energy contract until the end of 2020. In other words, to manage onboarding suppliers L1, T, and W.

From priority number two it was expected that at least supplier R had adopted a "green" energy contract by the end of this project (June 2021). The reason for this expectation was because supplier R - a rubber outsole manufacturer - consumed way less energy than supplier C - a big thermoplastic compounder -, thus projecting lower concerns about possible high electricity price difference when switching to the new contract. And, because the business share of FID PT was very much higher in supplier R than in supplier C, it would make it easier to leverage the "client-seller" situation in favor.

From priority three it was expected to have at least one out of suppliers L2, T, and X2, installing solar panels by the end of this project (June 2021).

In terms of the supply panel CO2e emissions, it was expected a drop from the initial 373 metric tons to 316 metric tons.

The Table 4.1 summarizes the expectations, where the "check" mark indicates a positive scenario, the "X" mark a negative one, and the question mark a unknown scenario.

Supplier Name	L1	L2	T	R	C	W	X1	X2	
Solar Panels	✓	?	?	X	✓	✓	X	?	
"Green" energy contract	✓	✓	✓	✓	X	✓	✓	✓	
Monthly electricity related CO2e emissions (metric tons)	0	0	0	0	316	0	0	0	316

Table 4.1: Expected FID PT supply panel energetic situation by the end of the project (June 2021).

4.2 rPVC Project

As exposed in the section 3.4 supplier W - a waders (fishing suit) manufacturer - produces annually 80 metric tons of a residue that contains 91% PVC and 9% PET. The waste is generated in long scraps, stored in cardboard boxes, and sent to landfill.

On the other side, there is supplier T - a thermoplastic injected footwear manufacturer - highly experienced in the injection of different kinds of flexible PVC. Besides this, it possesses the proper machinery for fragmentation of thermoplastics - used for indoors recycling -, separation of light textiles from thermoplastics and dehydration of thermoplastic pellets.

On one hand, there is a source of waste that contains valuable resources being discarded and on the other, the infrastructure and the know-how to fix it exists.

The proposed solution is that the PVC waste starts to flow to the supplier T facilities where it could be incorporated in the injection mixture to produce PVC boots A and B. But, since this rPVC (recycled PVC) project was starting from scratch, firstly it was necessary to prove the viability of the concept and to identify early technical specifications and production chain-related challenges.

For a preliminary testing, the proposed actions were that supplier W ships residues of PVC to supplier T. In turn, this one breaks them into 3-4 mm long pieces (pellet size), and if necessary enhances - by means of extra processes - the properties of the shredded material before it gets mixed with original PVC pellets to be injected. Once the boots were produced they would be sent to a laboratory for mechanical tests.

Since the upper part and the outsole of boots A and B are injected in two stages, it was chosen that the PVC residue from supplier W would only be incorporated in the upper part for both models tests, since this part is less rigorous on the technical specifications and makes up a bigger percentage of the total boot's weight, allowing for higher integration of PVC residues.

It was agreed to start with model A and then proceed to model B. Concerning the compositions, it was discussed with the thermoplastic engineer and with the product engineer of the boot models A and B that the following compositions should be tried in the upper part while maintaining the original outsoles: **30%** rPVC and **50%** rPVC.

4.2.1 Expected results

The main expectations from the preliminary testing on boot models A and B were to be able to produce the entire boot, validate that the injection molding machine can handle a percentage of the PVC waste with some PET mixed with, validate the integrity of the mold, and get a satisfactory adhesion between the upper part and the outsole.

Since the residue material from supplier W was 91% PVC and 9% PET, there were some concerns about PET effects not on the mechanical properties because the percentage was low, but on the color homogeneity.

It was also expected on both models an increase in hardness and density on the upper part, as the PVC residues were denser and harder than the boots'.

4.3 Leather-Rubber Project

As explained in the section 3.4, suppliers L1, L2, and X1 were sending to landfill a combined total of 371 metric tons of tanned leather waste per year.

The proposed solution to reduce this number or even bring it to zero was that one could incorporate such residues in the rubber outsole of a shoe. This way it would be possible to avoid disposing of leather waste in landfills and save costs on rubber.

This Leather-Rubber project also started from zero, therefore the first actions would be to prove the concept, identify early technical specifications and production chain-related challenges.

As exposed in the section 3.1 supplier R supplies rubber outsoles to supplier L1. Besides that, they are located near each other and the transport of outsoles between them is assured by supplier R trucks. Therefore there was already an established internal flow easy to work with and predict.

It was suggested that the preliminary testing would take off with supplier L1 and R. A leather shoe model was selected within the ones produced at supplier L1 and the objective would be to incorporate the leather waste from the production of the leather upper in the outsole of that same model. The leather would be properly shredded down to a maximum of 3mm in length at supplier L1 facilities, shipped it by the internal flow of trucks to supplier R, and there it would be incorporated with rubber to produce the outsoles. Then, the rubber outsoles would be sent to supplier L1 to produce the finished shoe.

The Figure 4.1 demonstrates how this model would work.

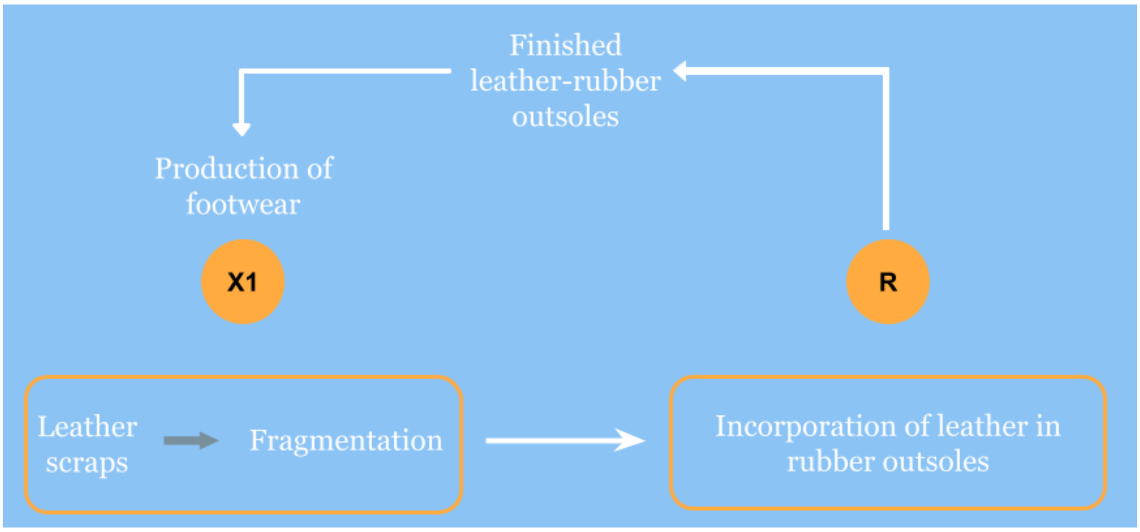


Figure 4.1: Leather-Rubber project model.

After analyzing literature on Rubber-Leather composites [64][65] and meeting with the author to discuss what percentage of leather should be incorporated, it was agreed that the viable maximum would be 10% in weight. Therefore it was proposed that the initial tests would be done with **5%** and **10%**.

4.3.1 Expected results

The most important expectations for both 5% and 10% compositions of leather in rubber outsoles were to guarantee proper rubber vulcanization without making many changes to the original process, confirm the reliability of the internal flow between supplier L1 and R, validate the shredding process at supplier L1 and the rubber-leather mixture at supplier R, and finally being able to produce the outsole.

It was also expected for both compositions a loss in elongation at break and breaking load parameters that would be worst in the outsoles with 10% leather since a higher presence of leather fragments in a rubber matrix increases the number of tension concentration points. The density of both compositions would also increase since the leather was denser than the rubber used.

Chapter 5

Results and Discussion

In this Chapter the results for each proposed solution are presented: energetic transition, rPVC project, and the Leather-Rubber project. A discussion of each result and an explanation of the potential financial and environmental gains are also included.

5.1 Energetic transition

As of the end of this thesis project (June 2021), the FID PT supply panel energetic situation is the one presented in Table 5.1.

The priority one goal of securing all FID PT FG suppliers consuming electricity 100% from renewable sources ("green" energy contract) was partially achieved by the end of 2020 and remains untouched until June 2021. Suppliers L1 and T were able to make the transition, but supplier W did not. To comprehend this unsatisfactory result it was important to understand that supplier's W vision was not include the adoption of this electricity contract but rather to expand in great dimension the already existing solar panel installation which would enable saving electricity costs and boost renewable energy consumption.

The priority two goal of guaranteeing all FID PT component suppliers with a "green" energy contract by the end of 2021 did not make any progress as of the end of this project. Supplier R is ready for the transition but, because of contractual reasons, the shift will only be possible in the coming months. Supplier C's situation is quite different, FID PT's business share is very low in comparison with any other supplier included here, thus not allowing to put much pressure on the matter. Besides this, supplier C is a huge consumer of electricity which did not help finding financially attractive deals.

Regarding priority three of getting FID PT FG suppliers to begin installing solar panels for onsite electricity production for self-consumption, the expected result was accomplished successfully because supplier X2 was able to install solar panels in the meantime. Moreover, suppliers L1 and W already have plans to expand their own solar installation, and supplier T has already settled a contract for a future solar installation. Supplier L2 is still apprehensive regarding the financial investment while the COVID-19 pandemic is still present, making this the main reason for its delay.

The difference between the expected results and the final ones is only due to suppliers R and W. The monthly reduction goal in CO2e emissions across the panel of 57 metric tons was 70% achieved. The end result was a monthly reduction of 40 metric tons instead. Furthermore, it is relevant to point out that the FG suppliers who maintain a "green" energy contract are eliminating between 30-78% of their CO2e emissions related to electricity consumption.

Future efforts will be needed to make the priority two and three objectives real, but fortunately, the topic of the energy transition is becoming more and more relevant within the industry and a major point of consideration for clients.

Supplier Name	L1	L2	T	R	C	W	X1	X2	
Solar Panels	✓	X	X	X	✓	✓	X	✓	
"Green" energy contract	✓	✓	✓	X	X	X	✓	✓	
Monthly electricity related CO2e emissions (metric tons)	0	0	0	11.3	316	6	0	0	333.3

Table 5.1: FID PT supply panel final energetic situation.

5.2 rPVC Project

The two tested compositions on boot models A and B upper parts, at supplier T, were a mixture of 30% rPVC and another of 50% rPVC. The outsole was injected with the original type of PVC used for each boot model. For every composition in each boot model were produced between 12 and 18 boot samples.

In order to achieve a clear understanding, the results will be treated separately for each boot model.

Boot model A was the first to be produced. Initially, the PVC residues sent by supplier W to supplier T were shredded down to the proper size (3-4mm long), and agglomerates of free PET fibers were created from this process. The samples with 30% rPVC in the upper part of boot A were produced and it was quite noticeable the presence of PET fibers on the upper part surface and slightly darker small stains that indicated high humidity content in the mixture material.

After these first issues the shredded PVC residues were submitted to an air-based separation machine where the lightweight agglomerates of free PET fibers were removed - the difference is shown in Figure 5.1 - and then it was dehydrated to lower the humidity content. However, there was still PET bound to the small PVC pieces.

With "cleaner" PVC residues, the 30% rPVC composition was repeated for boot A and then it was produced the 50% rPVC one. The partial removal of the PET fibers and water allowed for almost complete elimination of noticeable PET fibers on the boot's surface and the small stains.

Figure 5.1: Shredded supplier W PVC waste without removal of free PET fibers (left) and processed ready for injection rPVC mixture after the removal of free PET fibers (right).

All the properties in Appendix A for boot model A were tested in the laboratory and the results are displayed in the Appendix B.1. A summary of the results is the following:

- The **30% rPVC** composition in the upper part without the removal of free PET fibers produced a boot with an outsole/upper part bond strength lower than the specifications, therefore unacceptable. In the upper part, the density was slightly above the specification and the hardness was inconclusive. The elongation at break did not reach the minimum necessary. All other parameters were within the specifications.

- The **30% rPVC** composition in the upper part with the removal of free PET fibers produced a boot with better outsole/upper part bond strength values than the 30% rPVC composition without the removal of free PET fibers, but still not enough to be acceptable. The density was slightly higher than the specification and the hardness was well above the acceptable values. The elongation at break was compliant with the specification and this difference from the previous composition is thanks to a less presence of PET in the mixture. All other parameters were within the specifications.

- The **50% rPVC** composition in the upper part produced a boot with more and lower values of outsole/upper part bond strength than the previous composition, which were extremely not acceptable. The density and hardness were higher than the specification and higher than the last composition. The elongation at break properties fell very short from the tolerable values and lower than the second 30% rPVC composition. All other parameters were within the specifications.

Boot model B samples were made with the "cleaner" PVC residues and the upper part showed a homogeneous color from the start without any detectable defects. The laboratory tests included all the properties in Appendix A for this boot model and are displayed in the Appendix B.2. A summary is provided as follows:

- The **30% rPVC** composition created a boot with an outsole/upper part bond strength lower than the specification. The upper part surpassed the required density and hardness tolerances. The elongation at break was also compromised, not being able to reach the minimum value. All other parameters were within the specifications.
- The **50% rPVC** composition in the upper part produced a boot with low values of outsole/upper part bond strength, but surprisingly better than the 30% rPVC composition. The density and hardness were well above the desired range of values and higher than the other composition. The elongation at break did not achieve the minimum value and was lower than the 30% rPVC composition. All other parameters were within the specifications.

The preliminary testing of both boot models A and B proved to be possible to produce such models with a 30% and a 50% incorporation of PVC residues from supplier W, in the upper part. Furthermore, the injection molding machine operated within the already used values of temperature and pressure for the production of the original boot models, and the integrity of the mold was not compromised, which means that in terms of the injection process no big changes will be needed, though just a small production batch will better confirm this assumption.

Although this was a preliminary testing of this circular economy model, it was possible to draw some concrete technical conclusions for both boot models.

There is definitely an issue in terms of bond strength between the rPVC upper part and the outsole in both boot models that is due to the different chemical properties of both parts. This issue worsens with a higher concentration of rPVC in the upper part in model A, and was also expected to do the same in model B. The 50% composition in model B proved otherwise, achieving better results on this property than the 30% one. Such scenario is controversial and might indicate that there was an error during the production or the laboratory tests. A repetition of model B's compositions will be needed.

This bond strength problem might be possible to tackle if the outsole can also have the same percentage of PVC residue so the chemical bonding between the outsole and upper part can occur more successfully. Additionally, lower PVC waste incorporation rates can also reduce this issue. And ultimately, it could also be corrected by modifying the injection mold texture to gain more bonding area to improve the adhesion between the upper part and outsole.

The increased hardness and density are due to the PVC waste from supplier W that is harder and denser, which is also reflected in lower values of elongation at break since a harder material has less tenacity. Lower percentages of rPVC could help with this, and also switching to a new original PVC with lower density and hardness.

Attention must be paid to the four extra processes needed for this circular economy case: shredding of PVC waste, air-based separation of free PET fibers, dehydration of the final material, and mixing it with original PVC pellets. Such extra processes will demand extra labor, extra time, and consequently extra costs. However one shall not forget that this project will allow supplier T to cut down the purchase volume of new PVC by 80 metric tons annually which accounts for financial savings of around **€143,000**. Additionally, supplier W would save around **€6,000** annually in landfill fees that only tend to increase in the future.

In terms of CO2e emissions, the savings for supplier W and the environment would be **92.7** metric tons. Plus, there are the CO2e emissions related to the production of the 80 metric tons of new PVC that would be saved by incorporating the PVC residues from supplier W.

5.3 Leather-Rubber Project

The proposed incorporation of **5%** and **10%** rates of leather residues from supplier L1 in rubber outsoles made at supplier R was executed. The production chain worked as expected: the internal flow of trucks between the suppliers is reliable and predictable, supplier L1 is capable of shredding down the leather residues to the desired size (maximum 3mm long pieces), supplier R is capable of mixing them properly and the vulcanization process was done without changing any temperature or pressure parameters.

There was an issue derived from supplier R about the long-term integrity of the mold during the vulcanization process: since the leather pieces do not melt and pass into a liquid state like rubber does during the vulcanization, when the hydraulic press applies pressure and closes the two mold parts there might be a problem with leather pieces being "scrambled" into sharp edges and deforming the metal in those regions. This may require more frequent maintenance on the molds, but it can only be confirmed with a small production batch.

In terms of laboratory tests the results are presented in Appendix B.3, but for a better understanding:

- The **5%** incorporation of leather in rubber outsoles had their density respecting the specification value, but the elongation at break and breaking load well below the required values. However, flex resistance and abrasion resistance parameters were within the specifications.
- The **10%** incorporation of leather in rubber outsoles had an identical density to the previous mix, thus according to the specification. The elongation at break and breaking load fell shorter than the 5% mix and clearly not near the minimum required value. However, flex resistance and abrasion resistance parameters were compliant with the specifications.

In both 5% and 10% mixes, the most essential parameters for an outsole were respected: flex resistance and abrasion resistance. The density was satisfactory, but the elongation at break and breaking load were off the desired values as expected. These last two properties got worse results in the 10% composition.

The low values for elongation at break and breaking load parameters are due to the irregular shapes of leather pieces that can increase the appearance of tension concentration points around them. This could be corrected by reducing the size of the leather pieces.

Nonetheless, it is important to understand that in such a circular economy model the elongation at break and breaking load are not very important requirements for the behavior of a rubber outsole and it might be needed to reconsider them.

After the production of these outsoles, they were sent to supplier L1 where the shoes were assembled without any problems. Figure 5.2 illustrates the leather shoe model with an outsole with 5% leather and another one with 10% leather.

Figure 5.2: Leather shoe model with an outsole with 5% leather (top) and another one with 10% leather (bottom).

Considering just this leather shoe model that requires annually 32 metric tons of rubber for the outsoles, the implementation of this Leather-Rubber circular economy project can reduce the quantity of used rubber by 5% or 10% which means annual rubber cost savings for supplier R of €11,000 and €22,000, respectively. The extra processes of shredding the leather at supplier L1, transporting it, and mixing it with rubber at supplier R do not raise a concern about significant extra costs if any at all, since supplier L1 will also benefit from lower landfill fees and brand image, and the transport is supported by the already existing internal flow between both suppliers.

Moreover, an incorporation rate of 5% or 10% of leather residues would not only avoid related rubber extraction and production environmental impacts but also reduce the CO2e emissions related to the disposal of leather in landfills in **1.85** and **3.7** metric tons annually, respectively.

Even though this project only avoids 1.6 (5% leather incorporation) or 3.2 (10% leather incorporation) metric tons of leather from ending up in a landfill from the combined total of 371 metric tons from the FID PT supply panel, it is a big step in the right direction and a solution that can be implemented right now. However, there is one last open concern regarding the future end of life of such product: will the presence of leather in the rubber outsoles difficult the recycling of the outsole?

Chapter 6

Conclusions and Future Work

6.1 Conclusions

Humanity is starting to seriously realize the severeness of human-induced climate change and other environmental issues. This is mostly because it is already starting to feel the early consequences of a crisis that is forecasted to worsen in the future if humanity keeps neglecting its responsibility towards the surrounding environment and the species that inhabits together with.

This Master's Thesis project was part of Decathlon's environmental sustainability commitment to pursue its own ambitious goals for the year 2026 in line with the global Paris climate agreement. The work was conducted in the Footwear Industrial Division that constitutes one of many industrial activities of the Portuguese Decathlon's production department. In this division, it was considered the supply panel of eight finished goods and component suppliers that were in the first instance evaluated as a whole in order to identify critical sources of environmental impacts, which in turn is reflected in CO2e emissions.

The initial environmental assessment of the supply panel showed clearly that the two largest contributors to the total CO2e emissions were the consumption of electric power (76.3%) and the disposed waste at landfills (15.7%) by the suppliers. Therefore an initial energetic assessment was necessary to look in detail at each supplier condition. A landfill-destined waste assessment was also conducted and identified two types of waste that had significant weight on the total - tanned leather and PVC.

With these issues in mind one energetic transition strategy towards renewable energy consumption, and two circular economy models that aimed to incorporate the leather and PVC wastes in products made by the supply panel, were developed. The shift to the exclusive consumption of renewable energy was possible thanks to the adoption of electricity contracts that secured a consumption of electricity 100% from renewable sources, and the onsite installation of solar panels for self-consumption of electricity. Overall, there was a drop of 15% in the electricity consumption-related CO2e emissions of the supply panel, which accounts for a monthly reduction of 40 metric tons of CO2e emissions. Since one single supplier that did not transition represented 85% of the initial emissions of the supply panel a another view is relevant: more fairly, two out of five suppliers who did not have neutralized their electricity-related CO2e emissions did so. Additionally, one supplier out of five who did not have solar panels completed an installation, while two have settled plans to increase their current number of solar panels, and another is waiting for the installation to begin.

The developed circular economy solution inside the supply panel for the PVC waste consisted of incorporating this residue in two PVC boot models A and B. The work done included the preliminary testing of a 30% and 50% incorporation in the upper part of each boot model. It was concluded for both models that the concept is viable, the injection process seemed to occur normally and without big problems. However, there were some mechanical properties of both boot models that were not yet on the required values: the bond strength between the upper part and the outsole, the density, the hardness, and the elongation at break. Nonetheless, solutions were pointed out to tackle these issues, and if the implementation of this model takes place annual financial savings of €149,000 are expected - that are believed to cover the extra costs of processing the PVC residue -, and the reduction of CO2e emissions of well more than 92.7 metric tons yearly.

The circular economy solution for the leather waste comprised the incorporation of this material in a rubber outsole of a select leather shoe model. Similar to the previous project, this one also attempted a preliminary testing of 5% and 10% incorporation of such residue in the rubber outsole. The essential technical parameters for an outsole were respected, but other properties were not. It is believed that the solution can be ready to implement if less important technical specifications can be reconsidered. If so, and in specific just for the selected model, it is possible to achieve financial savings of more than €11,000 (5% rate) or €22,000 (10% rate) yearly, and CO2e emissions reductions of 1.85 (5% rate) and 3.7 (10% rate) metric tons annually.

To sum up, the energetic transition was partially successful as the main targets are still to reach. The most important action is to keep pushing for this transition, since electricity-related emissions were the highest contributor to the emissions of CO2e. The rPVC project showed promising results, but still needs more time and research to discover the best composition and process adaptations. The Leather-Rubber project seems to be ready for an implementation test.

6.2 Future Work

Regarding the energetic transition there is not much to add rather than to keep the efforts to achieving the priority two and three on time.

As to the rPVC project, it is important to repeat the work done in boot model B to investigate the improved bond strength values between the upper part and the outsole with the 50% composition, in comparison to the 30% one. For both boot models A and B new tests should be done with lower percentages of incorporated PVC waste on the upper part to assess how the technical properties are affected. Additionally, it is also suggested to try incorporating the PVC residues on the outsole so the adhesion between both parts can increase thanks to more similar chemical compositions. Reconsidering the type of PVC used to a softer one on the upper part might also help keep density, hardness, and elongation at break values within the specification. If the results are not still the desired ones, it would be wise to approach the thermoplastic compounder, so this one can process the PVC residues into a compound that arrives at the thermoplastic injected footwear manufacturer ready to be used. However, first it will be needed to separate the PET bonded with the PVC because the thermoplastic compounder is not capable of processing the PVC residue in that form.

In terms of the Rubber-Leather project, if the less important specifications for the rubber outsole of the selected leather shoe model are reconsidered, then a small production batch would be the next step to check for further challenges. Besides this, it is also suggested that the tests are repeated with the leather waste from the leather tannery since it is already in the form of fibers and might increase some mechanical properties [64]. More ambitiously, a shift to vegetable tanned leather would eliminate chromium-related environmental problems. And another option to be considered is a reverse tanning process capable of turning the leather material back into a biodegradable product.

Appendix A

Technical Specifications

Table A.1 presents the technical specifications for the upper part and the complete product for the PVC boot model A, while Table A.2 does the same for model B.

UPPER :

Test	DECATHLON STD	Detail	Unit	Commitment*	Tolerance
Density measurement for footwear material	DS 333		g/cm3	1,19	± 0.05
Determination of hardness of elastomers - shore A & D	DS 328	15"	shore A	65	± 3
Determination of Tensile stress strain properties for elastomers	DS 306		Mpa	8	min
Elongation at break	DS 306		%	250	min
Determination of Tear Strength for elastomers	DS 307		kN/m	9,5	min

COMPLETE PRODUCT :

Test	DECATHLON STD	Detail	Unit	Commitment*	Tolerance
Upper-sole adhesion	DS 303		N/mm	3	min

Table A.1: PVC boot model A technical specifications.

UPPER :

Test	DECATHLON STD	Detail	Unit	Commitment*	Tolerance
Density measurement for footwear material	DS 333		g/cm3	1,15	± 0.05
Determination of hardness of elastomers - shore A & D	DS 328	immediate 15"	shore A	65 59	± 5
Determination of Tensile stress	DS 306	2 senses	Mpa	7	min
Elongation at break	DS 306	2 senses	%	300	min
Determination of Tear Strength for elastomers	DS 307	2 senses	kN/m	9	min

COMPLETE PRODUCT :

Test	DECATHLON STD	Detail	Unit	Commitment*	Tolerance
Upper-sole adhesion	DS 303		N/mm	3	min

Table A.2: PVC boot model B technical specifications.

Table A.3 presents the technical specifications for the leather shoe model rubber outsole made by supplier R.

OUTSOLE TEST			
Outsole	Density (Picnometer)	DS 333A--2008	1,15 g/cm3 (+/- 0,05)
Outsole	Bennewart Flexion Resistance	DS-313	No damage after 50 000 cycles
Outsole (slab mold)	Abrasion resistance	DS 314B--2015	<180 mm3
Outsole	Tensile strain	DS 306C - 2014	minimum 14 Mpa
Outsole	Elongation at break	DS 306C - 2014	> 450%

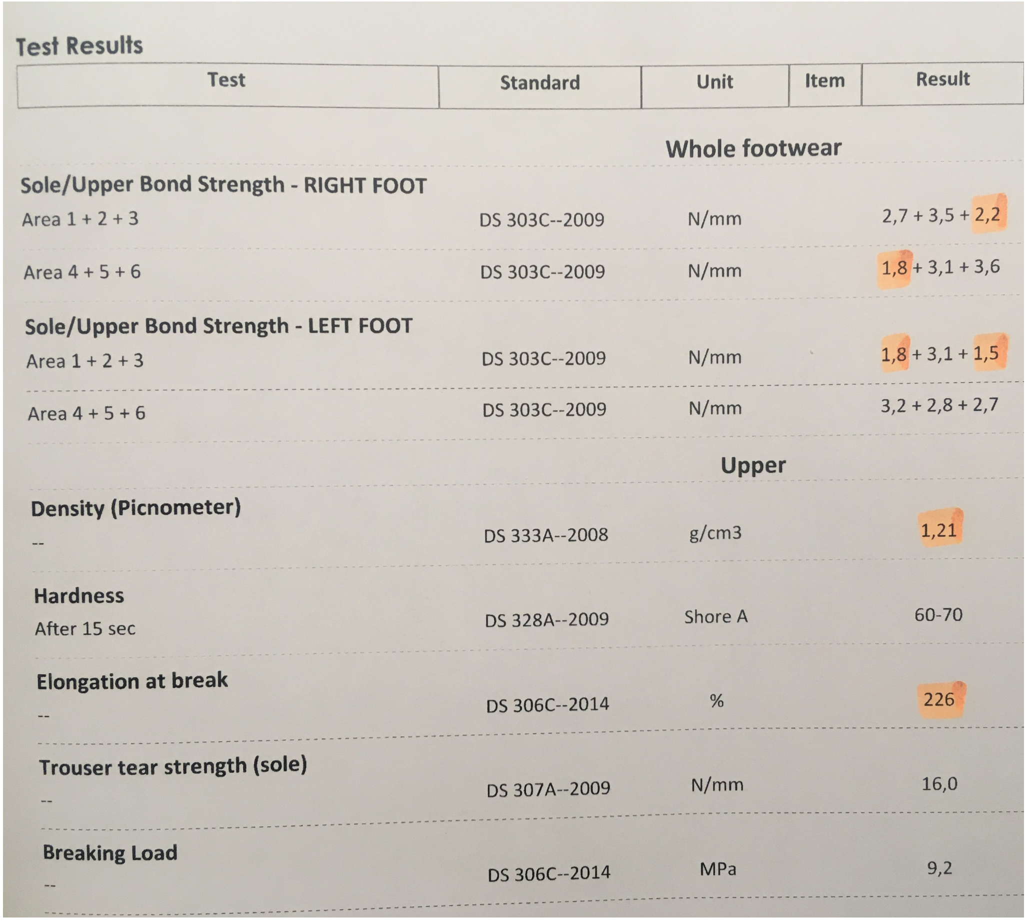
Table A.3: Leather shoe model rubber outsole technical specifications.

Appendix B

Laboratory Results

B.1 PVC boot model A

In Tables B.1, B.2 and B.3 it's displayed the laboratory results for the PVC boot model A with the incorporation of the different compositions discussed in the section 5.2. The highlighted values are the ones that differ substantially from the specification.



Test Results

Test	Standard	Unit	Item	Result
		Whole footwear		
Sole/Upper Bond Strength - RIGHT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		2,7 + 3,5 + 2,2
Area 4 + 5 + 6	DS 303C--2009	N/mm		1,8 + 3,1 + 3,6
Sole/Upper Bond Strength - LEFT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		1,8 + 3,1 + 1,5
Area 4 + 5 + 6	DS 303C--2009	N/mm		3,2 + 2,8 + 2,7
		Upper		
Density (Picnometer) --	DS 333A--2008	g/cm3		1,21
Hardness After 15 sec	DS 328A--2009	Shore A		60-70
Elongation at break --	DS 306C--2014	%		226
Trouser tear strength (sole) --	DS 307A--2009	N/mm		16,0
Breaking Load --	DS 306C--2014	MPa		9,2

Table B.1: Laboratory results of the PVC boot model A with 30% rPVC in the upper part without removal of free PET fibers.

Test Results

Test	Standard	Unit	Item	Result
		Whole footwear		
Sole/Upper Bond Strength - RIGHT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		3,2 + 2,9 + 3,3
Area 4 + 5 + 6	DS 303C--2009	N/mm		3,5 + 4,3 + 4,3
Sole/Upper Bond Strength - LEFT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		1,9 + 2,8 + 1,6
Area 4 + 5 + 6	DS 303C--2009	N/mm		3,7 + 3,4 + 3,1
		Upper		
Density (Picnometer)				
--	DS 333A--2008	g/cm3		1,21
Hardness				
After 15 sec	DS 328A--2009	Shore A		69-71
Elongation at break				
--	DS 306C--2014	%		254
Trouser tear strength (sole)				
--	DS 307A--2009	N/mm		15,6
Breaking Load				
--	DS 306C--2014	MPa		9,8

Table B.2: Laboratory results of the PVC boot model A with 30% rPVC in the upper part with the removal of free PET fibers.

Test Results

Test	Standard	Unit	Item	Result
Whole footwear				
Sole/Upper Bond Strength - RIGHT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		1,8 + 2,9 + 1,8
Area 4 + 5 + 6	DS 303C--2009	N/mm		2,5 + 1,8 + 3,8
Sole/Upper Bond Strength - LEFT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		1,4 + 1,5 + 1,2
Area 4 + 5 + 6	DS 303C--2009	N/mm		3,4 + 1,0 + 1,5
Upper				
Density (Picnometer) --	DS 333A--2008	g/cm3		1,22
Hardness After 15 sec	DS 328A--2009	Shore A		75-76
Elongation at break --	DS 306C--2014	%		201
Trouser tear strength (sole) --	DS 307A--2009	N/mm		12,0
Breaking Load --	DS 306C--2014	MPa		9,8

Table B.3: Laboratory results of the PVC boot model A with 50% rPVC in the upper part.

B.2 PVC boot model B

In Tables B.4 and B.5 are displayed the laboratory results for the PVC boot model B with the incorporation of 30% rPVC and 50% rPVC in the upper part, respectively. The highlighted values are the ones that differ substantially from the specification.

Test Results

Test	Standard	Unit	Item	Result
Whole footwear				
Sole/Upper Bond Strength - RIGHT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		3,5 + 2,2 + 2,6
Area 4 + 5 + 6	DS 303C--2009	N/mm		2,7 + 12,8 + 7,2
Sole/Upper Bond Strength - LEFT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		2,9 + 6,2 + 1,3
Area 4 + 5 + 6	DS 303C--2009	N/mm		6,0 + 12,0 + 15,0
Upper				
Density (Picnometer)				
--	DS 333A--2008	g/cm3		1,18
Hardness				
After 15 sec	DS 328A--2009	Shore A		68-69
Elongation at break				
--	DS 306C--2014	%		254 (+/-18)
Trouser tear strength (sole)				
--	DS 307A--2009	N/mm		11,4 (+/-1,3)
Breaking Load				
--	DS 306C--2014	MPa		8,1 (+/-0,4)

Table B.4: Laboratory results of the PVC boot model B with 30% rPVC in the upper part.

Test Results

Test	Standard	Unit	Item	Result
Whole footwear				
Sole/Upper Bond Strength - RIGHT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		4,7 + 1,7 + 4,7
Area 4 + 5 + 6	DS 303C--2009	N/mm		2,6 + 4,6 + 9,4
Sole/Upper Bond Strength - LEFT FOOT				
Area 1 + 2 + 3	DS 303C--2009	N/mm		11,6 + 6,5 + 5,1
Area 4 + 5 + 6	DS 303C--2009	N/mm		5,8 + 10,4 + 8,8
Upper				
Density (Picnometer) --	DS 333A--2008	g/cm3		1,20
Hardness After 15 sec	DS 328A--2009	Shore A		69-70
Elongation at break --	DS 306C--2014	%		233 (+/-14)
Trouser tear strength (sole) --	DS 307A--2009	N/mm		14,6 (+/-0,3)
Breaking Load --	DS 306C--2014	MPa		7,7 (+/-0,3)

Table B.5: Laboratory results of the PVC boot model B with 50% rPVC in the upper part.

B.3 Leather shoe model rubber outsole

In Tables B.6 and B.7 are displayed the laboratory results for the rubber outsoles with the incorporation of 5% and 10% of leather, respectively. The highlighted values are the ones that differ substantially from the specification.

Test Results

Test	Standard	Unit	Item	Result
			--	
Density (Picnometer) --	DS 333A--2008	g/cm3		1,19
Elongation at break --	DS 306C--2014	%		206 (+/-68)
Breaking Load --	DS 306C--2014	MPa		6,6 (+/-2,8)
Flex resistance Benwart 100.000 cycles	DS 313B--2009	mm		0,0 - no cracks
Abrasion resistance SOLE	DS 314A--2008	mm3		75 (+/-4)

Table B.6: Laboratory results of rubber outsole with 5% incorporation of leather.

Test Results

Test	Standard	Unit	Item	Result
			--	
Density (Picnometer) --	DS 333A--2008	g/cm3		1,19
Elongation at break --	DS 306C--2014	%		174 (+/-56)
Breaking Load --	DS 306C--2014	MPa		5,4 (+/-2,0)
Flex resistance Benwart 100.000 cycles	DS 313B--2009	mm		0,0 - with cracks
Abrasion resistance SOLE	DS 314A--2008	mm3		90 (+/-3)

Table B.7: Laboratory results of rubber outsole with 10% incorporation of leather.

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