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Digital Product Passport Policy in Europe: Potential Shift towards Circular Product Strategies

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I, Karel G.C. VAN ACKER, as supervisor of the student Joelle AYAN, hereby APPROVE the thesis entitled

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Abstract

In the midst of fast paced environmental degradation and climate change effects felt worldwide, electric and electronic waste, saturated with heavy metals and plastics, take a crucial role in soil, air, and water pollution, affecting in their turn human health. Policies targeting the reduction and better management of this type of waste have been at the center of attention of European policymakers. Digital Product Passport policy continues to receive interest in it's possibility to better manage and track electric and electronic appliances and their waste. This thesis thus evaluates what are the prospects of such policy in boosting circularity and circular product strategies, with a focus on home appliances, in Europe. A Delphi study, based on predictions and consensus from field experts was conducted. It was followed by an application of an interquartile range analysis, followed by a sensitivity (coefficient of determination R^2) and stability (Wilcoxon Signed-Rank Test) analysis. The results were the following: 1) Additional information from product passports will not influence the recovery, the rethinking, the refusal and the reduction of electric and electronic home appliances; (2) Additional information from product passports will slightly enhance the remanufacturing and reuse of electric and electronic home appliances; (3) Additional information from product passports will enhance the repair, repurposing, refurbishment, and recycling of electric and electronic home appliances. Moreover, 7.5% of home appliances put on market will be recovered; (2) 50% will be recycled; (3) 12.5% will be repurposed; (4) 15.5% will be remanufactured; (5) 21.5% will be refurbished; (6) 33% will be repaired; (7) 32.5% will be reused; (8) 20% will be rethought, and (9) 10% of home appliances put on the market will be refused. Finally, experts agreed that the implementation of DPP will most probably not change the price of spare parts of electric home appliances.

French Summary

Dans le contexte de la dégradation rapide de l'environnement et des effets du changement climatique ressentis dans le monde entier, les déchets électriques et électroniques, saturés de métaux lourds et de plastiques, jouent un rôle crucial dans la pollution des sols, de l'air et de l'eau, affectant à leur tour la santé humaine. Les politiques visant à la réduction et à une meilleure gestion de ce type de déchets ont été au centre de l'attention des décideurs européens. La politique du Passeport Numérique de Produit continue de susciter de l'intérêt dans la mesure où elle permet de mieux gérer et suivre les appareils électriques et électroniques et leurs déchets. Cette thèse évalue donc quelles sont les perspectives d'une telle politique pour stimuler la circularité et les stratégies circulaires de produits, avec un accent sur les appareils ménagers, en Europe. Une étude Delphi, basée sur les prédictions et le consensus des experts de terrain, a été menée. Elle a été suivie par l'application d'une analyse de l'écart interquartile, puis d'une analyse de sensibilité (coefficient de détermination R^2) et de stabilité (test de Wilcoxon Signed-Rank). Les résultats ont été les suivants : 1) Les informations supplémentaires provenant des passeports de produits n'influenceront pas la récupération, la remise en question, le refus et la réduction des appareils ménagers électriques et électroniques ; 2) Les informations supplémentaires provenant des passeports de produits amélioreront légèrement la refabrication et la réutilisation des appareils ménagers électriques et électroniques ; 3) Les informations supplémentaires provenant des passeports de produits amélioreront la réparation, la réaffectation, la remise à neuf et le recyclage des appareils ménagers électriques et électroniques. En outre, 7,5 % des appareils domestiques mis sur le marché seront récupérés ; (2) 50 % seront recyclés ; (3) 12,5 % seront réutilisés ; (4) 15,5 % seront remis à neuf ; (5) 21,5 % seront remis à neuf ; (6) 33 % seront réparés ; (7) 32,5 % seront réutilisés ; (8) 20 % seront repensés et (9) 10 % des appareils domestiques mis sur le marché seront refusés. Enfin, les experts s'accordent à dire que la mise en œuvre du DPP ne modifiera très probablement pas le prix des pièces détachées des appareils électroménagers.

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I. Introduction

The E-waste problem in the world and specifically in Europe is a growing concern: 44.7 metric tonnes of electric and electronic waste was produced in Europe alone in 2016 (Eurostat, 2016). Less than 40% of which gets recycled. In 2014, in the EU-28, e-waste collected for recycling amounted to 36.2%, and the remainder was divided between landfills (47.4%), backfilling (10.2%), and incineration (6.2%) (De Meester et.al, 2019). Belgium for example recycled 38.6% of its E-waste in 2020 (Eurostat, 2020). 32% of these are aimed at high-end applications, and the rest finds their way to low-end applications, landfills, and incinerators (De Meester et.al, 2019). The recycling of this waste category is done to retrieve mostly batteries and valuable metals (ferrous & non-ferrous metals: aluminum, copper), with the bigger mass of the product ending up in landfills (De Meester et.al, 2019). The valuables are then reintegrated into the industrial cycle. The manual dismantling and separation of e-waste in recycling facilities by workers, not only expose them to toxic chemicals and heavy metals that have disastrous effects on human health, but also heavily contaminate soil, water, and air (Long et al, 2016). Furthermore, outsourcing used/secondhand products from the United States and Europe to third-world countries (China, India, and African countries) remains a problem today: they often end up as waste and in landfills or in recycling facilities (Long et al, 2016). The aforementioned facilities engage cheap labor for recycling which is also problematic (Long et al, 2016). Thus, this raises ethical questions and considerations on the export of pollution and detrimental health effects from developed to developing countries, an issue currently being the center of scrutiny and research in many sectors (Long et al, 2016). The mapping of e-waste or end-of-life flows of this kind of waste is very unstructured since complementary flows, referring to unofficial flows, cannot be well documented, thus decreasing the accuracy and traceability of waste (Habib et, al., 2022). Moreover, the economic value gained from recycling e-waste is globally valued to be around USD1344.2 million in 2019 (Market Study Report, 2019), but this revenue is expected to start decreasing with first, the decrease in the size of electronic and electric materials, second, the decreased use of valuable metals and materials in EEE, and third, the increase in the difficulty of dismantling electric and electronic equipment. The aforementioned projects a decrease in recycling value, and a potential global trend skewing away from e-waste recycling. These projections are therefore contradicted by the current direction of European policymakers and laws to only incentivize e-waste recycling (for example EU WEEE Directive

2012) and not many of the remaining product strategies higher up on the circular economy scale, such as repair, refurbishment, repurpose, rethink, and reuse (Chen, 2021).

This thesis will thus look into the potential alternative policies, that could be adopted in Belgium, to increase the focus on R-strategies higher up on the circular economy scale such as repurposing and reusing. It aims to help policymakers shift the focus from recycling to more sustainable and efficient ways of treating E-waste. To conduct the aforementioned, a specific potential policy was chosen for analysis. In the European context, the potential policy to be investigated is the one concerning Digital Product Passports. The European Commission is increasingly showing ambition towards adopting this policy, which will take part in the EU's Green Deal and Circular Economy Action Plan, under the 3 initiatives of 1) The Sustainable Product Initiative, 2) The Circular Electronics Initiative (EU Digital Strategy), and 3) The Data Act, (Europa, 2022). The digital product passports will contain information about each component of a product on the European market to increase opportunities for reuse, recovery, and recycling (Europa, 2022). It will primarily focus on three key value chains: Electronics (consumer electronics), ICT, and Textiles (Europa, 2022). This will be achieved by the identification of the most relevant and transparent information about a product, while respecting intellectual properties, to facilitate its management throughout the supply chain and in end-of-life processes, both by users and workers (Europa, 2022). This comes in hopes of helping improve the traceability of products well after recycling, keeping their value, and fighting against greenwashing (Taylor, 2021). Digital Product Passport policies have not yet been fully applied and tested, but similar policies and initiatives already exist, such as the Flemish "Gebouwendossier", consisting of a construction file detailing a building's management, floor plans, photos/videos, complaints, and reports. This building file is also present in the Netherlands, and it can help give insight into the way of bringing together the digital product passport. Applying the concept of DPP will require legislators to tackle issues concerning first the intellectual property mentioned earlier, second the details needed to be included in them, and third the transferability and the different products on the market (Taylor, 2021).

Through the literature review conducted, some gaps found were the foundation for tackling these issues and initiating the work on this thesis project; and they include lack of data and studies around the digital product passport, indicating the novelty of this topic and confirming the need to conduct new research about it. Moreover, when looking at the current numbers of e-waste and electronics undergoing a certain product strategy, research only focuses on recycling, recovery and preparation for reuse, with some early numbers on repair. This also due to the difficulty in tracking electronics and e-waste whereabouts and end-of-life cycles, especially when they end up in developing countries' illegal landfills.

Thus, this thesis' research question revolves around: How will the implementation of the Digital Product Passport policy in Europe have a potential in boosting the shift towards more circular product strategies regarding electric and electronic home appliances? A specific focus will be made on electric and electronic home appliances ranging from smartphones and laptops to washing machines and refrigerators, since the policy targets this category of products, and data about them is more available. The objectives behind this questioning are:

- To investigate which circular economy product strategies can be fostered with the adoption of the DPP policy?
- Will the DPP policy influence the price of spare parts of electric and electronic home appliances?
- Can a prediction of how many percentage of electric and electronic home appliances will undergo a certain circular product strategy be made?
- Is there consensus between experts from governments, academia, and industry, working in these fields, around the topic of DPP and circularity boosting?

In order to carry on with the study, the methodology adopted was based on a quantitative study relying on a two round Delphi survey shared with experts in the field of circular economy, industries specialized in electronics, and governmental policymakers. The surveys explore the predictions that experts in these fields can foresee in regard to Digital Product Passports in order to draw what potential circular product strategies could be targeted. The results of the surveys were analyzed using the Interquartile Range (IQR), and then the two rounds were compared to each other to assess if consensus between experts was reached around the questions asked. Sensitivity and stability analysis were thus run to achieve the aforementioned.

The paper will thus first present a literature review discovering the business-as-usual scenarios related to electronics and e-waste management in Europe, to later be related to circular economy and already existing policies in the EU. The minimal existing information on product passports will also be presented. The details of the methodology used to answer this research question will be communicated. Results from the Delphi surveys will thus be presented and analyzed using the sensitivity and stability analysis.

II. Literature Review

A. Electronics & E-waste

To understand the contributions of product passports to the sustainability of the economy, it is important to understand the current practices towards boosting the circularity, or not, of products. The focus of this thesis falls on electric and electronic appliances and the waste they generate; thus, the aforementioned will be explored in relation to this category of products as a case study. This chapter summarizes the business-as-usual scenarios in regard to electronic and electric home appliances consumption, production, and waste management in Europe, as well as the ways in which e-waste contributes to the deterioration of our health and the planet's nature.

1. Context

Today's technological world is looped in the vicious loop of hyper consumerism driven by the intensive production and creation of cutting-edge technologies. Tech giants worldwide compete to unveil new, advanced, and updated electronics (i.e., phones) yearly to meet market expectations (EEA, 2021). Thus, driven by these expectations is marketing-induced obsolescence and a high turnover of appliances per capita due to failure either in the eyes of the consumer or because of the inconsistency of the old with new software (EEA, 2021). The rate of electric and electronic appliances put on the market per year keeps increasing, arriving at 20kg per capita, on market, in 2019 (Eurostat, 2019). The aforementioned highlights the continuously shortened lifetimes of appliances, where now, most have approximately 2.3 years less than their designed (manufacturer's intended lifetime of the product) or desired (the time consumers aspire for a product to last) lifetimes (EEA, 2021). For example, a smartphone's actual lifetime is 1.8 years, its designed one is two years, and its desired one is 5.2 years (Wieser et al., 2015). While a television's actual lifetime is 7.3 years, its designed one is 25 years, and its desired one is 11 years (Kalyani et al., 2017). Trying to keep up with this ongoing technological revolution and modern life's requirements, vast quantities of products are going obsolete or reaching their end of life, participating in increased numbers of what is known as electric and electronic waste (EEA, 2021). This electronic garbage, often known as e-waste, refers to abandoned electrical or electronic gadgets (Forti et al., 2020). E-waste includes used electronics meant for rehabilitation, reuse, resale, salvaging (functioning and repairable electronics), and recycling through material recovery (raw materials like copper, steel, plastic, or similar), or disposal (Forti et.al., 2020). However, their garbage impedes the EU's efforts to lessen its environmental imprint. The European Union categorizes E-waste into four main categories (Eurostat, 2020):

(1) large domestic equipment (i.e., cooling and freezing units),

(2) small home appliances (i.e., water kettles, blenders…),

(3) IT and telecommunications equipment (i.e., displays, phones, laptops), and

(4) consumer equipment and photovoltaic panels (i.e., radios, cameras…).

The "waste" refers to residue or material that is discarded by the buyer rather than repurposed, including leftovers from reusing and recycling activities (good, recyclable, and non-recyclable). Several public policy activists use the terms "e-waste" and "e-scrap" interchangeably to describe all excess electronics (Forti et.al., 2020). The European Union and its member states follow the European Waste Catalog (EWC), regarding the categorization of e-waste and its level of hazardousness. EWC is a list of standardized and harmonized ways to describe and refer to the different categories and sorts of wastes. The EWC provides a vague definition of what constitutes hazardous electronic waste (EWC Code 16 02 13*), forcing "waste operators" to use the Hazardous Waste Regulations for a more precise description and thus better handling (Eurostat, 2010; IT Green, 2013).

2. Current Numbers

To delve deeper into the European context, the following will inspect the evolution of production, consumption, and management of electronics and e-waste in the European Union’s nation-states between 2016 and 2021.

To start off with some global numbers, and with 48.2 million tonnes created in 2016, e-waste is considered the "quickest waste stream in the world" (Balde, 2017), equivalent to 4500 Eiffel Towers (Balde, 2017). In 2018, an estimated 50 million tonnes of e-waste were recorded, coined by the UN as a "tsunami of e-waste". It is worth at least $62.5 billion yearly (World economic forum, 2019). The majority of worldwide e-waste in 2019 was composed of small equipment (17.4 Mt), large equipment (13.1 Mt), and temperature exchange equipment (10.8 Mt) (GEM, 2020). Screens and monitors (6.7 Mt), small IT and telecommunications equipment (4.7 Mt), and lamps (0.9 Mt) accounted for a lesser proportion of total e-waste created in that same year.

In 2019, the world created a massive amount of e-waste (53.6 Mt, with 7.3 kilograms on average per capita) (GEM,2020). This figure is expected to rise to 74 Mt by 2030 (ECA, 2021). To zoom in on Europe, in 2019, e-waste generated accounted for 12.0 Mt (42.5 % of total generated waste) and led the way for per capita numbers, at 16.2 kg. Regarding e-waste collection, only 5.1 Mt was officially documented to have been gathered in Europe, that exact year.

The legally recorded collection and recycling of e-waste was 9.3% of the 53.6 Metric tons created globally, while the destiny of 44.3% remains unknown, with its locations and environmental effect differing throughout different areas of the world (WEEE forum, 2021).

However, nations with national e-waste laws, regulations, or policies have risen from 61 to 78 since 2014. For example, in Belgium, in 2018, the e-waste collection rate was 49.4%, accounting for a collection of approximately 10 kg/per capita from private households (ECA, 2021). Globally, an estimated 57.4 Mt of e-waste was created in 2021. According to estimates in Europe, where the topic has received the most attention, 11 of 72 electronic equipment in a typical family are no longer in use or are damaged. Another 4 to 5 kg of unwanted electrical and electronic items are stockpiled in Europe each year before being dumped. By 2021, fewer than 20% of e-waste has been recovered and recycled (WEEE forum, 2021).

3. Impacts of E-waste

E-waste has been gaining much attention from environmentalists, governmental bodies, and policymakers in the last couple of years. To understand the reasons behind this increased awareness the following will first outline the multitude of hazardous constituents of these appliances, as well as existing regulations; to later investigate the informal practices related to the management of e-waste and its environmental and health consequences.

Electric and electronic equipment typically contain dangerous materials, including heavy metals like mercury, cadmium, and lead, chemicals like chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and flame retardants. It also contains rare and valuable metals such as gold, copper, and aluminum, which is the main reason behind collecting and recycling electric and electronic appliances, alongside the batteries involved. These valuables are then reintegrated into the industrial cycle and economy. In the flows of e-waste produced in 2019, about 71 kt of plastic containing BFR (Brominated Flame Retardants) was produced alongside. BFRs are employed in appliances to decrease the material's flammability; they may be seen, for instance, in computer cases, printed circuit boards, connections, relays, wires, and cables (McPherson et.al., 2004; Herat, 2008). Because it is expensive to separate plastic containing polybrominated diphenyl ethers (PBDEs) and polybrominated biphenyls (PBBs) from other types of plastic, recycling BFR-containing plastic, among them PBDEs and PBBs, poses a significant problem for e-waste recycling. Recycled plastic with PBDE and PBB levels over 0.1% is prohibited from being utilized in producing any goods, including EEEs. To prevent the emission of dioxins and furans, compliant recyclers often incinerate plastic containing PBDEs and PBBs under regulated circumstances. (EFSA, 2021)

On the other hand, if incineration is not eco-friendly, such compounds can endanger human health and the environment. Some of these contaminants are toxic and persistent; biomagnification and risk assessment studies have shown that they can harm the kidneys, cause several skin disorders, and damage the nervous and immune systems. As a result, some of these contaminants have been banned in Europe. (European Parliament, 2011).

Regulations regarding the proper handling, recycling, and dismantling of e-waste, and the toxicity of materials involved, are mostly developed and respected in the EU's nation-states and North America (Li, 2020). Most consequences on health, environment and societies due to e-waste are seen in third-world countries, and poorer nations, such as China, India, Africa, and Latin America (Li, 2020). The following is due to outsourcing used/secondhand products from the United States and Europe to China and India and other countries (Li, 2020). Even though the Basel Convention prohibits the export and disposal of waste and hazardous substances between countries, second-hand selling renders electric and electronic appliances most likely to end up in landfills, dismantling centers, or recycling facilities (Long et al, 2016). The aforementioned facilities, located in developing countries, either engage cheap labor for recycling or are illegally managed, putting at-risk children and untrained personnel, which is also problematic (Long et al, 2016). Thus this raises ethical questions and considerations on the export of pollution and detrimental health effects from developed to developing countries, an issue currently being the center of scrutiny and research in many sectors (Long et al, 2016). 70% of the world's electronic and electric garbage ends up in a specific town in China: Guiyu, but only 25% of the aforementioned end up in official and formal recycling centers and is dismantled by trained and protected personnel (Li, 2020). According to UNEP only 20 % of e-waste is formally recycled (UNEP, 2019). Thus, the mapping of e-waste or end-of-life flows of this kind of waste is very unstructured since complementary flows, referring to unofficial flows, cannot be well documented, thus decreasing the accuracy and traceability of waste (Habib et al., 2022).

In these informal landfills and recycling centers, toxic materials and pollutants leach down and infiltrate the soil, water, and air surrounding them, heavily polluting the environment and ecosystems. Hazardous chemical discharge into the environment can readily be implicated in environmental processes such as bioaccumulation, food contamination, and extensive ecological exposure, resulting in larger-scale risk dissemination (Li et.al., 2020). Metal-polluted sediments and higher dissolved metal levels have been recorded in rivers near e-waste recycling operations. Polluting particles (PM) in dust and fumes emitted by open-air burning operations can readily disseminate across regions, resulting in various health effects on local populations. Hazardous compounds originating from e-waste, on the other hand, act in the soil-crop-food route, which plays a key role in heavy metals exposure to residents. Even abandoned e-waste recycling operations might still be a source of pollution, releasing trace metals, plastics, and POPs into the environment and endangering human health. (Long et.al., 2016; Li et.al., 2020). Studies on the harmful health implications of e-waste have become more prevalent. These studies have highlighted the risks to human health associated with exposure to well-researched poisons like lead. According to a recent study, unregulated e-garbage recycling has been linked to many harmful health impacts. These include negative birth outcomes (Zhang et.al., 2018), altered neurodevelopment (Huo et.al., 2019), negative learning outcomes (Soetrisno et.al., 2020), DNA damage (Alabi et.al., 2012), negative cardiovascular effects (Cong et.al., 2018), negative respiratory effects (Amoabeng et.al., 2020), negative immune system effects, and cancers (Davis et.al., 2019).

Information on how many individuals is exposed to e-waste is limited. The number of individuals engaged in unauthorized e-waste management globally and in afflicted nations is only roughly estimated (EMG 2019; ILO, 2019; Perkins, 2014; Prakash et.al., 2010; Xing et.al., 2009). However, it needs to be made clear which techniques were employed to get these estimations. They frequently ignore community members who do not participate in informal recycling, youngsters, or those exposed to contaminants due to environmental pollution. There may be a risk to populations in hotspots for recycling e-waste. However, the absence of a concentrated area for e-waste recycling does not imply that a nation does not have an e-waste problem. E-waste is a component of a wider waste context and is frequently picked up door to door or dumped with other types of rubbish at landfills. In communities, worldwide, waste-pickers, who are among the poorest and most vulnerable, are exposed (Gutberlet & Uddin, 2017).

B. Circular Economy

The burden created from the over-production of electric and electronic appliances and e-waste weighs heavy on management systems currently put in place. Solutions and policies fostered to solve these issues for a more sustainable management of these products and their waste revolve around circular economy application and circular product strategies. Thus, the following will first explore the definition of circular economy and its product strategies, to later tackle the existing European circular economy policies and a criticism of circular economy practices in the EU. Finally, the relationship of e-waste and circularity will be studied.

1. Context

In the last few years, consumers' environmental awareness appears to be increasing. Especially after the SARS-CoV-2 pandemic's positive and tangible ecological impacts on one hand, and the palpable environmental and climate disasters around the planet on the other hand (i.e.: the Australian wildfires, the coral reef extinction, and the oil spillage, etc.). Surges in industrial, business, and governmental interest in greener approaches and solutions were noted around the globe (Ellen MacArthur Foundation, 2020). "Green recovery" has thus dotted recuperation plans all over the world, from the European Green Deal (no net emissions of greenhouse gasses by 2050) to the Japanese Circular Economy Collaboration plan with the World Economic Forum, as well as the United States under Biden's administration with the American Rescue Plan focused on "building back better" in terms of the environment, public health and infrastructure (Nandi et.al., 2021). The post-pandemic rush to recovery has highlighted the crucial role governments and policymakers have, in building a more resilient inclusive economy that can withstand global disasters and threats; it revealed the current system's vulnerability. These pre- and post-COVID-19 economic revival plans are all commonly overtaken by one concept; Circular Economy, seen, across the continents, as the solution for a more durable and green future balancing society's health, environment, and economy (Kirchherr et al., 2017; Ellen MacArthur Foundation, 2020; Nandi et.al., 2021). A focus has also been made on the crucial need for digitalization, specifically digital technologies concerning sustainable business models, which will be discussed in more detail throughout this thesis (Bouchon & Toumi, 2020).

2. Circular Economy and the R-strategies

Before delving more deeply into the legal frameworks and governmental actions regarding the elaboration and implementation of the circular economy, it is crucial to look into the plethora of definitions assigned to it. The concept of circular economy is the “buzzword” of current market trends, as its mention provides an instant promise of environmental responsibility to consumers or clients (Lehmann, 2021). The promotion of the circular economy as the magical solution to a greener system respectful of the environment has distorted and deteriorated the definition, goals, and application of this concept, which were already very complex, broad, and unclear (Römph & Cramer, 2020). This is due to the fast propagation of greenwashing practices and marketing methods to attract the environmentally conscious clientele and to fit in the market demand, further clouding up the beneficial implications of the circular economy under the umbrella of sustainable development (Kirchherr et al., 2017). In an analysis of 114 circular economy definitions, Krichherr et al. (2017) highlight scholars’ ambiguity and disagreement around a single encompassing definition of the term, especially with having “sustainable development” as an umbrella concept, which in itself holds controversy due to its vagueness and theoretical inclinations (Van den Brande et al., 2011; Peltonen, 2017). By compiling all the different variations, a rather complete definition arises and takes the form of the following: “It’s an economic system that substitutes the concept of "end-of-life" with reducing, reusing, recycling, and recovering materials in the production/distribution and consumption cycles. It functions at the micro (i.e. products, companies, consumers), meso (i.e. eco-industrial parks, industry sectors), and macro levels (i.e. city, region, nation, and beyond) to achieve sustainable development, so ensuring environmental quality, economic prosperity, and social equality for present and future generations. It is made possible by innovative business concepts and responsible consumers” (Kirchherr et al., 2017; Ellen MacArthur Foundation, 2022). This comprehensive explanation is not found in scholarly articles, since the implementation of the concept is usually divided into two directions: either the waste hierarchy approach or, in more recent years (after 2012), the systematic approach. The waste hierarchy approach is related to the R-frameworks, and encompasses the 3R (reduce, reuse, recycle), 4R (reduce, reuse, recycle, recover), all the way to the 9R one (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) (Potting et al., 2017). Even though only 30% of definitions mention waste hierarchies, the most mentioned frameworks are the ones revolving around reducing, reusing, and recycling (3R), as found in the European Union Waste Framework Directive, with minimal mention of the more elaborate and circular strategies

(Kirchherr et al., 2017). An example of the latter is Lansink's Ladder, which focuses on prioritizing the adoption of the most environmentally conscious solutions while setting policies, found at the top of the ladder, such as renouncing, rethinking, reducing, reusing, and repurposing, before passing down to more harmful strategies (Kirchherr et al., 2017).

Refuse (R0), Rethink (R1), Reduce (R2), Reuse (etc), Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover are the acronyms for the 9R's. These strategies' implications may seem straightforward or even apparent but understanding them and knowing when to apply them is crucial.

The following, will define the R-strategies and demonstrate how the R-framework may be used at various points in a building's lifetime to keep it from depleting resources as it reaches the end of its useful life (Potting et al. 2017, Mast et al. 2022);

R0 Reject: The advantage of the product can also be achieved in other ways; thus consumers are not required to use it. For instance, small distances don't always need the usage of a bicycle; the distance can alternatively be done on foot.

R1 Rethink: Different customers utilizing a product without purchasing it, increases its intensity of usage. Bike sharing in many places is one illustration of this that is becoming more and more popular.

R2 Reduce: Increasing efficiency can also result in the usage of less material to get the same result. One way to do this is to reduce the number of materials needed to make the final product through design modifications or by streamlining the requirements for the production processes through process optimization. For instance, based on the painting procedure, paint powder and energy can be saved.

R3 Reuse: When the reuse method is applied, a product that hasn't changed is sold to a third party that uses it again. Flea markets are a well-known example in the area of private bicycle sales. The eBay website functions as a virtual equivalent of flea markets.

R4 Repair: The product is restored to its initial condition through repair, enabling the function to be carried out once more and the fulfillment of a benefit. The option of supervised bicycle repairs, such as mending the bicycle tube, is available at public bike stores.

R5 Refurbish: The term "refurbishment" refers to product enhancement. These are updated to the most recent standards of technology in addition to being mended. A bicycle lamp's illumination can be improved by using an LED bulb.

R6 Remanufacture: Remanufacturing includes integrating parts that are still entirely intact into new full goods, as opposed to refurbishing. Cycling enthusiasts frequently use their old saddles with new bicycles, for instance.

R7 Repurpose: The repurpose approach discusses the potential for incorporating parts into a whole new product to produce an entirely new benefit. Containers are frequently used as an example in this. For instance, jam jars can be reused as pickle containers or pots.

R8 Recycle: It makes sense to recover the raw materials utilized through recycling methods when items or components cannot be used any longer. The product design has already had a significant role in determining the recycling options. Recycling isn't always achievable in the sense that recycled materials can't re-enter the cycle and take the place of the original raw materials used to make the product in question. Downcycling is the term used when materials can no longer be recycled in the same quality. Therefore, the objective of a high recycled content in goods is also more crucial than the goal of high recyclability at the end of the service life for maximizing material recycling. Butyl rubber may be recovered from the bicycle inner tube and used to make new inner tubes for bicycles. Aluminum bicycle frames can be recycled so that the metal may be used to make new bicycle frames, while fiber-reinforced materials can only be recycled by downcycling (for the end-of-life treatment of fiber-reinforced plastics, Oliveux et al. 2015).

R9 Recover: Since the recovery strategy does not result in material recycling, it does not fall within the traditional definition of circular value recycling strategies. As a result, it is listed last on the prioritized list. The re-cover approach is still frequently used in today's practice when recycling raw materials is not (yet) technically or economically feasible. In these circumstances, waste must be converted into usable energy. This non-circular strategy usage may be mainly prevented by product design, improved recycling technology, and acceptable governmental framework conditions. Plastic bicycle components, for instance, are burned at waste incineration facilities to create electricity from this garbage.

The R0 to R2 strategies seek to prevent or decrease the use of raw materials in manufacturing. This is accomplished by rendering products obsolete since the functions associated with them are fulfilled elsewhere. Furthermore, raw material input is minimized through greater manufacturing efficiency or higher usage intensity; Customers will receive the same total benefit while using less raw resources. R3–R7 strategies try to maintain raw commodities inside the economy. Benefits can be supplied without further raw material extraction by reusing or reusing products or product components. If R0 to R7 cannot be used, raw materials from goods

or product components that are no longer functioning can be secured using the R8 and R9 strategies. The goods or parts are destroyed during this operation. The requirement for primary raw materials can be decreased by recovering secondary raw resources. In other words, less resource extraction is required for raw materials (Mast et al 2022).
Companies use the R-strategies as instruments for spotting circular potentials. In addition, they serve as a categorization and list of suggestions for further action, based on whose traits the most circular business models may and should be developed. However, it should be understood that the R-strategies do not stand for all possible responses to problems. Companies must still build a strategy that will help them achieve their objectives, determine how to further develop the business concept from this strategy in a unique and tailored way, and produce creative circular business models as a result.

Firms and enterprises wanting to adopt a circular approach lack proper guidance towards other R-strategies than recycling, higher up on the CE scale, which leads them to assume the easiest path to achieve this label, with zero resistance from their part, continuing with the business-as-usual model, thus further contributing to the greenwashing trend witnessed nowadays. Often, companies religiously focus and adopt recycling as the holy grail solution, where they focus and improve the strategy around a small part of their operations without disturbing the whole supply chain (George et al., 2015; Lacy et al.,2015). Promoting strategies other than recycling equates to promoting a decrease in consumption and thus an "economic" decrease in growth which does not fall in line with the current systems of production (George et al., 2015; Lacy et al.,2015). This is mirrored by the literature and policymakers' focus on recycling since it's the most mentioned strategy (79% of definitions of CE), with less focus on others higher up the circularity ladder such as repair, repurpose, and reuse for example. This tendency appears to be misleading since recycling is increasingly linked to downcycling because it hinders the quality of materials over time, thus still participating in waste generation. Hence a waste hierarchy approach could be better for tackling and rethinking the ensemble of production, distribution, and consumption methods.

3. Role of Europe in CE & CE Policies

European policymakers and both existing and prospective regulations, regarding waste and resource management, all are based on circular economy pillars. To explore the latter, and connect it with electric and electronic waste management policies, this chapters delves into plans, initiatives and regulations such as the Circular Economy Action Plan, the Eco-Design Directive, the EU Ecolabel Directive, the EU green public procurement, and the Circular Electronics Initiative.

The new circular economy action plan (CEAP) was approved by the European Commission in March 2020. It is one of the cornerstones of the European Green Deal, the continent's new plan for sustainable development. The EU's shift to a circular economy will relieve the strain on the planet's natural resources and provide employment and sustainable growth. Additionally, it is necessary to stop the loss of biodiversity and reach the EU's 2050 climate neutrality goal. Initiatives are announced for every stage of a product's life cycle in the new action plan. It strives to reduce waste and keep the materials utilized in the EU economy for as long as feasible, It also targets product design, stimulates circular economy practices, and promotes sustainable consumption (EC, 2015).

In co-creation with economic players, consumers, citizens, and civil society organizations, this Circular Economy Action Plan offers a future-focused strategy for building a greener and more resilient Europe. It attempts to hasten the radical change demanded by the European Green Deal while advancing the circular economy initiatives (begun in 2015). With the help of this strategy, the regulatory environment will be simplified, made appropriate for a sustainable future, and the new opportunities created by the transition will be fully used with the fewest restrictions on individuals and enterprises (EC, 2015).

The sustainability characteristics of products are already somewhat addressed by EU initiatives and regulation, either on a required or optional basis. The Eco-design Directive is notable for its success in regulating energy efficiency and some circularity elements of energy-related items. While having a wider reach than voluntary initiatives allow, instruments like the EU Ecolabel and the EU green public procurement (GPP) requirements have a less impact (EU GPP, 2020). In reality, there is no complete set of standards to guarantee that all goods sold in the EU market are ever more sustainable and pass the circularity test (Regulation (EC) No 66/2010).

The main goal of this legislative endeavor is to expand the scope of the Eco-design Directive transcend energy-related items in order to ensure that the Eco-design framework is applicable to the widest variety of products conceivable and that it achieves circularity (EU GPP, 2020).

The Commission thought about creating sustainability guidelines and other suitable means to govern the following areas as part of this legislative initiative and, where appropriate, through supplementary legislative measures (Directive (EU) 2019/882):

→ Boosting product energy and resource efficiency, addressing the presence of hazardous substances in goods, and improving product durability, reusability, upgradeability, and reparability.

→ Increasing the number of recycled materials in goods while guaranteeing their functionality and safety.

→ Allowing high-quality recycling and remanufacturing.

→ Decreasing environmental and carbon footprints.

→ Limiting single-use items and combating early obsolescence.

→ Putting a stop to the destruction of durable products that have not been sold.

→ Promoting business models that reward producers for maintaining ownership of the product or accountability for its performance during its entire lifespan.

→ Using digitalization of product information's potential, including techniques like digital passports, tagging, and watermarks.

→ Valuing goods according to their various sustainability performance, particularly by tying rewards to high performance levels.

The EU Ecolabel Directive, the Product Environmental Footprint approach, and the EU GPP criteria have all created standards and guidelines on which the evaluation of the Eco-design Directive and subsequent work on particular product groupings will draw, where necessary. The implementation of obligatory regulations will be taken into consideration by the Commission as a way to improve both the sustainability of goods and services. Along the value chain, from production to use to end of life, the potential for introducing criteria related to environmental and social factors will be carefully considered, taking WTO regulations into account. For instance, improving the accessibility of specific goods and services can enhance product reusability and durability while also promoting social inclusion (A New Circular Economy Action Plan, 2020).

The EC will also (EC, 2020) (1) promote the effective and efficient use of the new sustainable supply chain framework; (2) create a shared European Dataspace for Smart Circular Applications containing information on value chains and products;(3) intensify efforts to enforce relevant sustainability standards for items put on the EU market in collaboration with

national authorities, including through coordinated inspections and market monitoring operations.
A crucial component of the sustainable product policy framework is giving customers control, empowering them and giving them options to save money. The EC proposed a revision of EU consumer law to ensure that consumers receive reliable and pertinent information on products at the point of sale, including information on their lifespan and the accessibility of repair services, spare parts, and repair manuals, in order to increase consumer participation in the circular economy. The Commission will also think about establishing minimum standards for sustainability labels, emblems, and informational aids in order to further reinforce consumer protection against greenwashing and premature obsolescence (COM, 2020).
The EC also seeks to create a new "right to repair" and take into consideration new horizontal material rights for consumers, such as access to repair services, availability of spare parts, and, in the case of ICT and electronics, upgrading services. The Commission will consider potential adjustments in relation to the role that guarantees can play in supplying more circular products as part of the assessment of Directive 2019/771(A New Circular Economy Action Plan, 2020).
It will announce a "Circular Electronics Initiative" utilizing both current and future tools in the area of electronics and ICT. This program will encourage extended product lives and, in keeping with the new sustainable goods policy framework, will take the following steps, among others: (Special Eurobarometer 503, 2020)

→ Regulations for ICT and electronics, including mobile phones, tablets, and laptops, are being implemented under the Eco-design Directive to ensure that products are made with energy efficiency, durability, repairability, upgradeability, maintenance, and recycling in mind. Additional information on this will be included in the future Eco-design Working Plan. Unless the industry comes to an ambitious voluntary agreement over the next six months, printers and consumables like cartridges will also be included.

→ Prioritize the implementation of the "right to repair," including the ability to update out-of-date software, in the electronics and ICT industry.

→ Regulations on chargers for cell phones and other comparable devices, such as a standard charger, increased charging cable sturdiness, and financial incentives to separate the buying of chargers from the purchase of new gadgets.

→ enhancing the collection and handling of waste electrical and electronic equipment, such as by looking at opportunities for a European Union-wide take-back program to return or sell back old mobile phones, tablets, and chargers.

→ Review EU regulations limiting the use of hazardous materials in electrical and electronic equipment and offer recommendations to strengthen compliance with pertinent laws like REACH (Directive 2011/65/EU) and Eco-design (Regulation (EC) No 1907/2006).

Since the 1970s, significant advancements in waste management have been pushed by EU trash legislation and funded by EU resources. To adapt them to the circular economy and the digital era, they must be continuously modernized. In order to reduce waste, boost recycled content, promote safer and cleaner waste streams, and ensure high-quality recycling. Additionally, as part of a larger package of waste mitigation strategies in the framework of a reform of Directive 2008/98/EC, the Commission will propose waste reduction objectives for particular streams. The Commission will also stimulate information exchange and best practices in trash recycling, improve the implementation of newly established standards for extended producer responsibility schemes, and give incentives. By 2030, the entire quantity of trash produced must be drastically reduced, and the amount of residual municipal garbage must be cut in half (A New Circular Economy Action Plan, 2020).

4. Criticism of CE

The circular economy framework has difficulties linked to the viability of the idea. The concept of eliminating waste lies at the heart of the framework. If the vision can be universally implemented in some industries, like manufactured goods, and materials can be used longer and reused before being disassembled and remanufactured, in other industries it may be more challenging to completely close the loop. For example, paper recycling is only allowed to be recycled a certain number of times. Asbestos and Mercury are two specific types of hazardous waste that cannot be reused and must instead be contained off the cycle, they may also come to a dead end. According to the second rule of thermodynamics, all spontaneous processes irrevocably scatter energy (and hence matter) into ever more chaotic states, causing the loss of both quantity and quality of elements and making complete loop closure unattainable (Bechtel, 2013). Impurities of old materials can only be reduced to a certain degree in R strategies nowadays. The European Commission, for example, established long-term recycling targets of up to 70%, with the remaining 30% being classified as non-recyclable materials, in its initial effort to define a circular economy regulation. This shows how well lawmakers are aware of these restrictions. Beyond the issue of achievability, there is the concept of attractiveness for enterprises. Attempting to achieve 100% recyclability may be unproductive in the current environment, for example, if the cost of recuperation is greater than the value of the materials recovered. The absence of incentives in the current regulatory context does not always make pursuing a circular economy goal attractive for everybody.

The circular economy concept lacks a detailed account of the social dimension of sustainability, such as meeting human needs and geopolitical implications. Its concepts are largely designed from a commercial standpoint, with equal emphasis on environmental and economic advantages. Social benefits are frequently missing. New industrial activities in a Circular Economy, such as refurbishing or recycling, need more human labor because these procedures are not always standardized. If this can offer job possibilities (EMF, 2019), it is not certain that the jobs are created locally. A centralized recycling plant on the other side of the planet might alternatively be the result of a circular economy approach, with little possibility for local job development. Furthermore, abuses of power, unhealthy or unfair labor and living circumstances, or a disregard for human rights may continue to erode people's fundamental necessities on a worldwide scale. As a result, the circular economy concept does not always address all aspects of sustainability.

The circular economy framework neither offers precise guidance on how to execute the idea nor particular criteria to help the selection of initiatives. It is challenging to offer generic instructions due to the fact that the circular economy's implementation differs greatly for various goods and marketplaces and requires tailored or specialized methods (FEA, 2022).
A circular economy plan may also include challenging trade-offs. Circular economy principles may eliminate items that are not totally recyclable when choosing resources for a production process. However, the environmental advantages of some materials (such as fewer corrosive materials and lightweight components) may exceed the drawback of non-recyclability (FEA, 2022).

5. CE & E-waste

To dive back into the electric and electronic home appliances and their position in the circular economy paradigm, the material design of EEE is quite intricate. It contains more than 69 elements from the periodic table, including “CRM” or critical raw materials (CRM, 2019) like cobalt, palladium, indium, germanium, bismuth, and antimony, as well as noncritical metals like aluminum and iron. The e-waste “mine” should be considered a significant source of secondary raw materials in the context of a circular economy. Which opens ways to enhance secondary resource mining and lessen the demand for virgin materials, which is intricate with problems of primary mining, market price changes, material scarcity, availability, and access. In this sense, countries could reduce their material demand safely and sustainably by recycling their electronic trash. Globally, only 17.4% of e-waste is recognized as being formally collected and recycled. So collection and recycling rates must be increased (CRM, 2019).

On one side, the recycling industry frequently faces difficulties in recycling materials and high recycling prices. For example, the scattered use of some elements in products, such as germanium and indium, makes it difficult to retrieve them, and the products are neither built nor developed with recycling principles. On the other side, base metals, such as gold, are employed in several gadgets, including PCs and mobile phones, and their concentration is rather high: "7% of the world's gold may currently be contained in e-waste, with 100 times more gold in a tonne of e-waste than in a tonne of gold ore" (UNEP, 2019). (280 grams per ton of e-waste). E-waste separation and recycling techniques can be economically viable, especially if done manually and with material losses of around 5%. (Deubzer, 2007). Thus, for devices having large concentrations and quantities of precious metals, separate collection and recycling of e-waste can be economically viable. However, most CRMs still have extremely poor recycling rates, which may be increased for valuable metals by better e-waste collection and pre-treatment.

Moreover, the economic value gained from recycling e-waste is globally valued at around USD 1344.2 million in 2019 (Market Study Report, 2019). Still, this revenue is expected to start decreasing with first, the decrease in the size of electronic and electric materials, second, the decreased use of valuable metals and materials in EEE, and third, the increase in the difficulty of dismantling electric and electronic equipment. The aforementioned projects a decrease in recycling value, and a potential global trend skewing away from e-waste recycling. These projections are therefore contradicted by the current direction of European policymakers and laws only to incentivize e-waste recycling (for example EU WEEE Directive 2012) and not any of the remaining R-strategies higher up on the circular economy scale such as repurposing, rethinking, and reuse (Chen, 2021),

To address the difficulties associated with managing e-waste, the United Nations University - SCYCLE program (UNU-SCYLE), the International Solid Waste Association (ISWA), and the International Telecommunication Union (ITU) teamed up in 2017 to establish the Global E-waste Statistics Partnership in close cooperation with the United Nations Environment Program

(UNEP). This program intends to gather information from nations and create a worldwide e-waste database to monitor changes over time.

Since the release of the Global E-waste Monitor in 2017, an increasing number of e-waste-related policies, laws, and ensuing regulations have taken more upmarket design and manufacturing features into account as well as waste management considerations.

This is consistent with worldwide legislative initiatives to promote a circular economy. A review of the current approaches, or at least a significant enforcement of the current laws and regulations, is necessary for response to the recently predicted probabilistic scenarios for e-waste development in 2050 and 2100 (Parajuly et al. 2019), which might lead to a doubling of the yearly e-waste creation in the next 30 years.

Additionally, the Extended Producer Responsibility (EPR) concept has generally been taken into consideration since the Global E-waste Monitor 2017 when drafting new laws and regulations throughout the world. With this, the manufacturers will also be in charge of the post-consumer phase of the lifetime of a product (Parajuly et al. 2019). Therefore, it was anticipated that EPR rules will stimulate product design that promotes recycling and reuse. But it is increasingly clear that most producers are only able to accept their accountability with a joint effort with other important stakeholders, including governments, municipalities, merchants, collectors, recyclers, and consumers. The astounding accumulation supports this view compared to the available inventory. Additionally, producers are becoming more interested in connecting with circular economy strategies rather than e-waste programs like StEP or the Basel Convention's PACE (Parajuly et al. 2019).

- → StEP initiative: the Solving the E-waste Problem (StEP) Initiative was established in 2007. Concerned with developing ecologically, economically, and ethically sound e-waste resource recovery, reuse, and prevention. It includes five task forces (TF) - "Policy," "ReDesign," "ReUse," "ReCycle," and "Capacity Building". (StEP, 2019)
- → BASEL convention: the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is a multinational agreement created to stop the trade in hazardous waste that is harmful to the environment and society. The treaty was made available for signing in 1989, went into force in 1992, and has now been ratified by 187 nations. E-waste frequently includes dangerous components (UNEP, 2022). The Convention, therefore, states that to safeguard public health and the environment, hazardous substances should not be exchanged freely like other commercial items. As a result, it provides a written notice and permission process for

all cross-border transfers of hazardous wastes. Because reuse extends the life cycle of EEE and thereby reduces the production of hazardous waste, the Basel Convention's regulatory exemption on equipment intended for reuse is completely compatible with its primary environmental purpose of minimizing waste generation. Reuse encourages the conservation of natural resources and, at the very least temporarily, eliminates the need for recycling or disposal by extending the useful life of electronics. However, the Basel Convention has long debated whether something is “waste” or meant for “reuse”, and a final agreement on the definition of waste has still not been reached. (UNEP, 2022)

The WEEE Directive (2012/19/EU), which governs the bulk of European e-waste, was adopted in 2012. Both Norway and the European Union have adopted this legislation. Other nations adopted the law, such as Iceland, Switzerland, Serbia and Bosnia, Herzegovina, and numerous Balkan nations. All kinds of e-waste were concerned by the; collection, recycling, reuse, and recovery strategies, set under the WEEE Directive. (EC, 2022).
As of 2018, according to article 7 of the WEEE Directive, a member state's yearly minimum collection rate must equal either 65% of the average weight of EEE placed on the market in the three years prior or 85% of the e-waste produced. In the European Union, private companies can collect e-waste from stores and municipalities using a highly developed compliant infrastructure. This infrastructure also allows for the recovery of recyclable parts from the collected e-waste and environmentally responsible disposal of residuals. (EC Europa, 2022).

The relatively long history of the EU with e-waste and the numerous laws that date back to early 2003, were the drivers behind establishing these infrastructures. Therefore, according to figures based on e-waste collection data provided for 2017, 59% of the e-waste created in Northern Europe and 54% of the e-waste generated in Western Europe are documented as being formally recycled. These percentages are the highest in the entire globe. A member state of the EU must collect 85% of the e-waste produced for the reference year 2019 or 65% of the EEE placed on the market from the three years prior. This means that recycling and collecting must rise even more to satisfy the requirements. (European Court of Auditors, 2021)
In 2021, Europe recycled 80% of the E-waste it collected. Between 2012 and 2018, Europe recycled, prepared for reuse, and incinerated (recovered) 87% of its collected e-waste, with 80% of the latter recycled. In 2017, 85% of large household appliances and consumer

equipment, 82% of small household appliances, and IT/telecommunication equipment were recycled or prepared for reuse (European Court of Auditors, 2021). No extensive data is available concerning the percentage of repair of electric/electronic home appliances, but some numbers suggest that only 2 to 5% of defective appliances get repaired. This number is also expected to increase due to the EU's right-to-repair policy. Moreover, 38% of newly purchased electric/electronic home appliances are due to the breakdown of old products. (European Court of Auditors, 2021; Laitala et.al., 2020)

In the end, the circular economy's paradigm pushes toward reducing e-waste by keeping the materials and the contained substances in the loop as much as possible for more mitigation of the EEE. This can be done through the increased use of the other R-strategies (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) (Potting et.al., 2019). In this sense, the EU seeks to advance circular economy concepts with the EU green deal, and the circular economy action plan, to improve the efficiency of the circular economy.

C. Product Passports

1. Context

Inadequate or absent information sharing between various stakeholders throughout value chains is one of the biggest obstacles to obtaining a CE. In this sense digitalization, including data and digital solutions, as part of the larger green and digital transitions under the European Green Deal, is an underutilized option for solving this dilemma. The digital product passport (DPP) is one digital instrument that needs special attention. Although there is still a lack of widespread understanding and knowledge of the DPP, the current developments could strongly support a CE. The EU unveiled the Sustainable Products Initiative (SPI) on March 30, 2022, as part of a new legislative package on the CE, paving the way for the widespread adoption of DPPs. To facilitate information sharing amongst the essential parties, including governmental agencies, businesses, consumers, and civil society actors, it is crucial to have a comprehensive policy framework on DPPs.

DPPs can be useful tools for facilitating easy access to and exchange of information on products. Producers, consumers, garbage operators, and law enforcement agencies may readily access and perhaps contribute pertinent and tailored details for other stakeholders by scanning the tag (for example, a QR code). This would have several advantages. For instance, convenient access to knowledge can encourage consumers to buy more circular things or teach repairers how to mend used equipment.

The SPI expands on the 2020 Circular Economy Action Plan and suggests legislation requiring manufacturers to implement DPPs as part of general eco-design specifications for specific items. It anticipates that DPPs will include rights to access, introduce, modify, or update the information, be interoperable with other DPPs to improve information transfer, and be coupled with unique product identifiers (i.e., codes similar to a personal identification number) (barre codes, tags). The DPP's content must adhere to open standards and be based on organized, machine-readable information.

2. DPP Definition

What really is a DPP? A "product passport" is a set of product-specific data that may be electronically accessed through a data carrier to "electronically record, compile, and disseminate product-related information across supply chain enterprises, authorities, and consumers," (European Commission. 2021). A product's origin, composition, and potential for repair and disassembly, as well as information on how the various parts may be recycled or disposed of at the end of their useful lives, would all be covered by the DPP. By using this information, circular economy practices like preventative maintenance, repair, remanufacturing, and recycling may be scaled up. Additionally, it educates customers and other interested parties about the sustainability features of goods and materials (European Commission. 2021).

All sophisticated circular economy plans, such as product refurbishing or widespread high-quality material recycling, rely on the availability of trustworthy and current data. The development of a fully functional digital circular economy information system must be seen as a critical precondition for increased resource efficiency and effectiveness (Berg et al. 2020). DPPs can serve as the primary data carrier for a product or material, containing both master data (product, manufacturer, composition, compounds of concern, toxicity, and source) and newly acquired data (use, modification, maintenance, and wear and tear). They can enable information monitoring and management on a product's or material's composition and life cycle. In an ideal world, such digital data management would allow for near-real-time monitoring of environmental effects (Berg et al. 2020).

Given the information required to completely construct a circular economy, the future DPPs may serve as the primary source of data and information. The interchange of stakeholder material and product information inside DPPs will be critical to their growth, as it will increase analysis and comprehension (Adsorn et al. 2021). Furthermore, such information exchange will give critical insights for future circular economy policies while also establishing the required level of openness. In addition, learnings from DPP data analysis might lead to improvements for stakeholders as well as policymakers, such as better-informed science-based objectives (Walden et al. 2021).

DPPs might help policymakers and public administration execute demand-side regulations on materials and products. These rules are critical for establishing a level playing ground for the transition to a circular and climate-neutral economy (GHG Protocol FAQ. 2021). DPPs might also help policymakers better grasp the consequences of new or altered sustainable development policies, which could enhance policy assessment. Furthermore, DPPs may enable or improve market monitoring, allowing EU domestic and imported product compliance to be properly monitored and enforced. The implementation of a DPP would provide a number of benefits (CISL. 2021);

• Access to credible and comparative product sustainability information for firms and regulators, as well as information to address broader product liability problems.

• Consumers' access to information that allows them to make better informed and sustainable decisions.

• Greater openness, traceability, and uniformity for all players in the value chain.

• Assistance for businesses to monitor and report on sustainability indicators and claims using a digital platform.

• A tool for stimulating creative thinking on circularity and new practices.

• Possibility of enabling the development of entirely new business models.

• New data sources that can help with long-term investing decisions.

• Making resource optimization and energy efficiency measures possible.

III. Methodology

In order to investigate the research question and assess the potential impacts of a regulation foreseeing digital product passports in regard to consumers' electronics, a methodology following a quantitative design, was put in place and will be discussed in the following chapter.

A. Context

Digital Product Passports have received much attention from European policymakers in the past few years. But still, more research and data are needed surrounding their feasible implementation and impacts on the market, as well as their potential contribution to the circular economy. This thesis thus aims to evaluate the usefulness of adopting a digital product passport policy in Europe and how it can contribute to boosting or hindering each of the circular economy's R-strategies: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover, with a focus on electric and electronic home appliances (consumer electronics, small and large appliances). The assessment of the economic and environmental impact of such policy constitutes the core objective of this research paper. Since the DPP policy does not exist yet, thus no complete data is available concerning its costs, benefits, feasibility, impacts, and potential drawbacks. Moreover, most data concerning the R-strategies is concentrated around recycling, recovery, and preparation for reuse, and minimal research focuses on the strategies higher up on the circular economy scale (ECA, 2021). The study area concerned is the nation-states of the European Union, with a focus on Belgium, the Netherlands, Germany, and France. This choice was due to the aggregation of policies paving the way for the potential adoption of the DPP policy, such as Gebouwendossier, Subsidies to re-employment (textiles), and the three European Initiatives of Sustainable Product Initiative, Circular Electronics Initiative, the Data Act, and the Battery Act (European Commission, 2022). This chapter will first present the research approach utilized in this paper, as well as details on the data collection process that was adopted and the means of analysis.

B. Research Approach

To study the environmental and economic impact of the DPP policy and to answer the research question, this research followed a quantitative approach to help quantify results to assess if the policy is worth to be implemented on a governmental and environmental level, boosting the shift towards circular strategies higher up on the circularity scale, in regard to electric and electronic home appliances. Following deductive reasoning, a cross-sectional study based on the data collection and analysis, which will be described in the next sections, was put together. The reason behind the choice of a mixed method, inductive, cross-sectional study rests behind the lack of studies and data on the topic of digital product passports and the novelty of the policy in question (Dalkey & Helmer, 1962; Van Schoubroeck et.al., 2021). The predictive and prospective nature of the research thus determined this research approach. (Recker, 2021)

C. Data Collection: Literature & Delphi Method

Data needed to proceed in this thesis was collected first through an extensive literature review on current business-as-usual scenarios in processing electric and electronic home appliances regarding some of the circular economy's R-strategies. Data and information already published on Eurostat, European governments' websites, and EPREL/SCIP databases, regarding the impacts of e-waste on circular product strategies, such as annual collection rates and R strategies efficiencies in Europe, will also be part of the study.

Moreover, constituting the data basis for this research, and to predict the possible implications and effects of the DPP policy, a Delphi survey method was put in place. The RAND Corporations created the Delphi method to find consensus among experts about a certain topic (Dalkey & Helmer, 1962). It is most commonly used in cases in need of prediction, where data is not available or researched yet, and can help draw conclusions around a certain topic, which is the case for DPP policy in regard to electric and electronic home appliances. It is a repetitive approach that allows professionals to interact anonymously by gathering opinions and developing follow-up rounds based on these opinions. It can be run through multiple rounds to delve deeper into the opinions, differences, and consensus with the chosen experts. The aggregated results of these Delphi surveys will be published. However, no personal relatable information, nor individual answers will be revealed. The entire Delphi method is fully anonymous (Okoli and Pawlowski, 2004). The first goal behind the creation of this survey was to explore how the different stakeholders, potentially impacted, see the DPP policy, and its potential and if they agree on the potential benefits or drawbacks. The second goal was to assess if the policy is seen to be implementable in Europe and follow the reverberations of the topic between experts.

In the frame of the aforementioned, a two-round Delphi study was conducted; 108 experts from around Europe, working in governments and policymakers (European Commission, Brussels, Walloon, and Flemish governments, etc.), industries (technology and electronics companies i.e.: Orgalim, Bosh, Samsung, etc.), environmental consultancy companies (Ecores, etc.), and academia, were contacted to take part in the first survey (Annex 1). To find the experts, desk research was conducted to find the relevant actors and stakeholders in the field of electronics. Contacts of sustainability, policy, and circularity officers, in said companies, were then retrieved through LinkedIn or companies' websites. Contacts with governmental institutions and policymakers in the European Commission were the product of networking between professors at KUL and employees in concerned companies. A total of 58 experts responded to the first survey, with 28 going through the whole questionnaire, and 22 showing interest in being contacted again for the second round. This Delphi survey was created, filled, and managed with Qualtrics Software. The first round was sent out on the 17th of August 2022, with a reminder sent out on the 21st of September 2022. It was concluded by the end of September. This round presented the needed definitions to proceed with the completion of the survey such as the DPP, and each of the R-strategies definitions. Questions revolved around the potential influence of the additional information from the DPP on each of the R-strategies, and how much electric and electronic home appliances will undergo each strategy (Annex 2). Questions about how much electronic/electric home appliances will undergo each strategy and how would that influence the price of spare parts (Annex 2) were also drafted. It also included a part about the demographics of the participants (Annex 2).

For the second round, tailored emails were sent to the 22 participants, including their personal responses to the first round. Another general set of emails was sent also to the exhaustive list of experts. It was put online and sent out on the 13th of October 2022; with a reminder sent on the 25th of October 2022. It was taken offline for analysis on the 31st of the same month. The second round was tailored according to the answers of the first one. Thus, it first presented the general results of the first round as well as some of the business-as-usual numbers regarding how e-waste is managed according to the R-strategies (Annex 3). The latter was included in order to ask some of the same questions from round one, but with providing the participants with some knowledge about the current e-waste and circular economy situation. The questions tackled revolved around the percentage of appliances affected by each circular economy strategy with additional information from the DPP, and the evolution of the price of spare parts (Annex 3). Out of 24 respondents, 14 experts answered the second round of the survey in full.

D. Data Processing & Analysis

In order to analyze the Delphi survey results, the processing of the data had to be first made. The results were downloaded through an Excel Sheet, cleaned (i.e.: participants who did not complete all the survey or answered most of the questions were removed), and classified. The analysis tool of choice was applied to the numbers through Excel as well; and it consisted of the Interquartile Range (IQR) as an inferential statistical tool (Birko et.al., 2015). The Interquartile Range (IQR) is a measure of the dispersion from the median that includes the middle 50% of the observations. As a result, a maximum threshold of IQR is established to determine whether consensus has been achieved using this measure. Consensus is considered to have been reached when the middle 50% of observations differ by less than the threshold (Birko et.al., 2015). The interquartile range is calculated by subtracting the third quartile value from the first quartile value:

$$\boldsymbol{IQR = Q3 - Q1}$$

Equation 1: IQR calculation

To determine the value of Q1 and Q3, the data should be ordered from low to high, then divided into four equal parts. The first value composes the first quartile Q1, under which lies 25% of the data; while the third value represents the third quartile Q3, or in other words, 75% of the data (Birko et.al., 2015). The interquartile range is the range of values between the 75th and 25th percentiles (75 - 25 = 50% of the data). The interquartile is considered a reliable measure since outliers have little influence on the statistic because they are not dependent on every value. Furthermore, the interquartile range is excellent for skewed distributions, and not normally distributed data (Birko et.al., 2015).

IQR is a quick and straightforward tool to analyze consensus, as it will pinpoint the high scores, and thus indicate in this case the R-strategies more likely to be affected by the implementation of the DPP policy, as agreed by the experts. In addition to being able to analyze the consensus of each round of the survey, it enabled the possibility to indicate the convergence in agreement from the first to the second round, using a sensitivity analysis. The use of a 5-point Likert Scale for the Delphi questions, ranging from decrease, slightly decrease, no influence, slightly enhance, and enhance; enabled the conversion to a range from -2 to 2, and thus suitable for IQR application. Moreover, the calculation of the median, which is the value that separates the upper and lower halves of a data sample, referred to as the middle value in a data set, can give insight on the central tendency of the responses.

$$\boldsymbol{Med(X)} = \begin{cases} \boldsymbol{X\left[\frac{n+1}{2}\right]} & \boldsymbol{if\ n\ is\ odd} \\ \boldsymbol{\frac{X\left[\frac{n}{2}\right] + X\left[\frac{n}{2}+1\right]}{2}} & \boldsymbol{if\ n\ is\ even} \end{cases}$$

Equation 2: Equation showing the calculation of the median

The combination of the central tendency (median) and the spread (IQR) of the responses, gives an idea about which answer the experts agreed or have consensus about or not. As for non-Likert scale questions, the IQR was used to determine the upper and lower range of the aggregation of 50% of the data.

$$\boldsymbol{Median + \left(\frac{IQR}{2}\right)}$$

Equation 3: Calculation of the upper range.

$$\boldsymbol{Median - \left(\frac{IQR}{2}\right)}$$

Equation 4: Calculation of the lower range

This was done using the median calculation for each question. By getting the upper and lower ranges, it was then apparent between which percentages 50% of the answers lie, the smaller the IQR, the lower the range is, and the more consensus there will be over that specific question.

As for the inter-round analysis, a sensitivity analysis was conducted in Excel, which is the biplot of the first and the second round. For the 10 questions, present in the 1st round and then repeated in the second one, the IQRs were plotted in order to get the consistency of the IQRs throughout the rounds, and to see how stable/sensitive the answers are. By drawing the general trend of the curve, the equation could be calculated, from which R^2 (coefficient of determination) is extracted. The goal from this is to compare the convergence in the two rounds. The R^2 value determines the quality of the linear regression between the rounds, in other words and the proportion of variance between them. It can tell if the results of the first round can explain and predict the ones of the second round. R^2 is a value between 0 and 1, the smaller and closer to 0 it is the more there is convergence in the opinions of the experts in this case.

Moreover, to further assess the sensitivity analysis, and the relevance stability analysis was performed, using the Wilcoxon Signed-Rank Test, which allows for determining if the difference between the two rounds is significant. When the distribution of the differences between the two samples cannot be assumed to be normal, this test is used to determine whether or not there is a significant difference between the two populations (Cunha et.al., 2022), for this study case, it is the two rounds of answers. The non-parametric version of the paired samples t-test is the Wilcoxon Signed-Rank Test. To run this test, through Excel, first, the difference between the IQRs of the 10 questions in both rounds, should be calculated; followed by a calculation of the absolute difference, a ranking of the absolute difference, as well as the positive and negative ranks for each question (Cunha et.al., 2022). Second, a calculation of the test statistic is performed, which is the smaller sum of the positive or negative ranks. The sample size is also necessary to conduct this test. If the test statistic number is less than the chosen critical value for the corresponding sample size, then the difference between the groups is significant. (Annex 4) (Cunha et.al., 2022).

IV. Results & Analysis

A. Demographics

The experts participating in the Delphi survey were carefully selected to create a representative sample spanning an array of experts in different fields of work and different positions of action in regard to the potential implementation of the DPP policy. The first round of the survey included some questions about the sample's demographics. The part including the personal information of the participants was composed of five questions: (1) in which country they are currently based, (2) to precise their gender, (3) their field of work, (4) their job position/ title, (5) their self-assessed level of expertise in the topics.

Results related to this part showcase the diversity in the chosen sample and thus its credibility. First, the 28 final respondents to the first round were mostly from Belgium (24 participants), while the remaining four, were divided between Italy (1), Finland (2), and Austria (1). 17 of the participants, were males, 8 were females, and 3 preferred not to indicate (Figure 1).

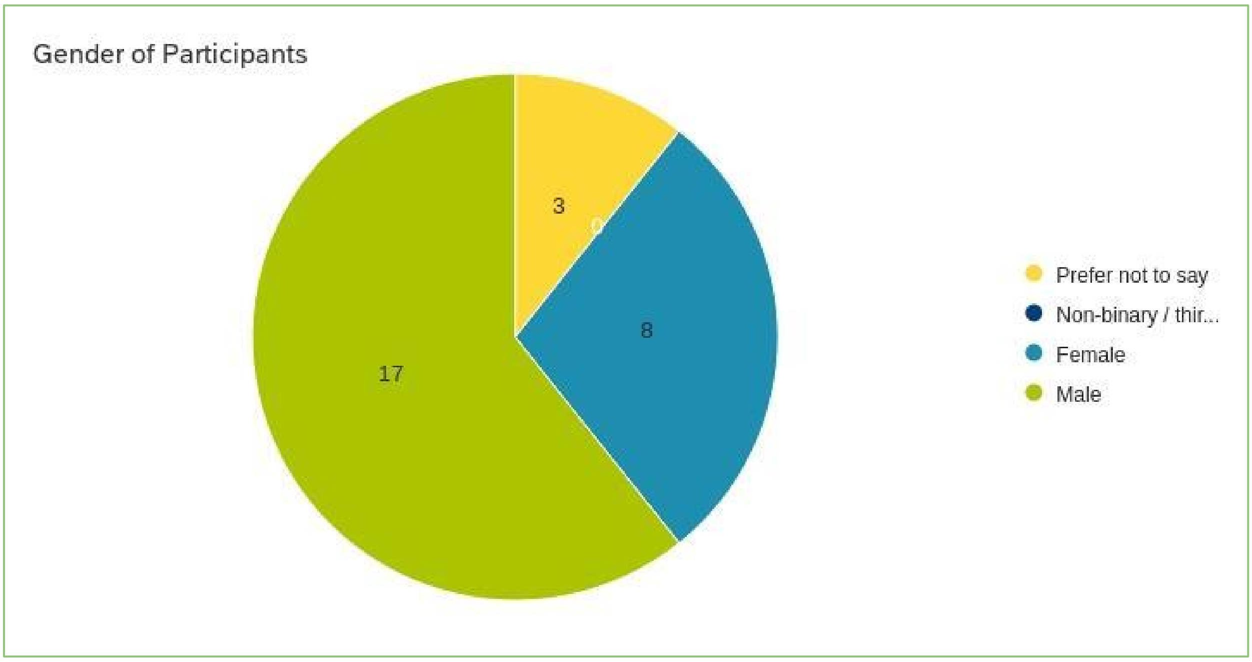

Figure 1Graph showing the gender distribution of the Delphi survey participants. (Qualtrics, 2022)

As for their field of work, 12 participants work in the government (can encompass EU commission, Belgian governments, and European governments); 8 of the experts belonged to the industry sector, while 5 work in academia, 2 in consultancy, and 1 expert works for the NGO sector (Figure 2).

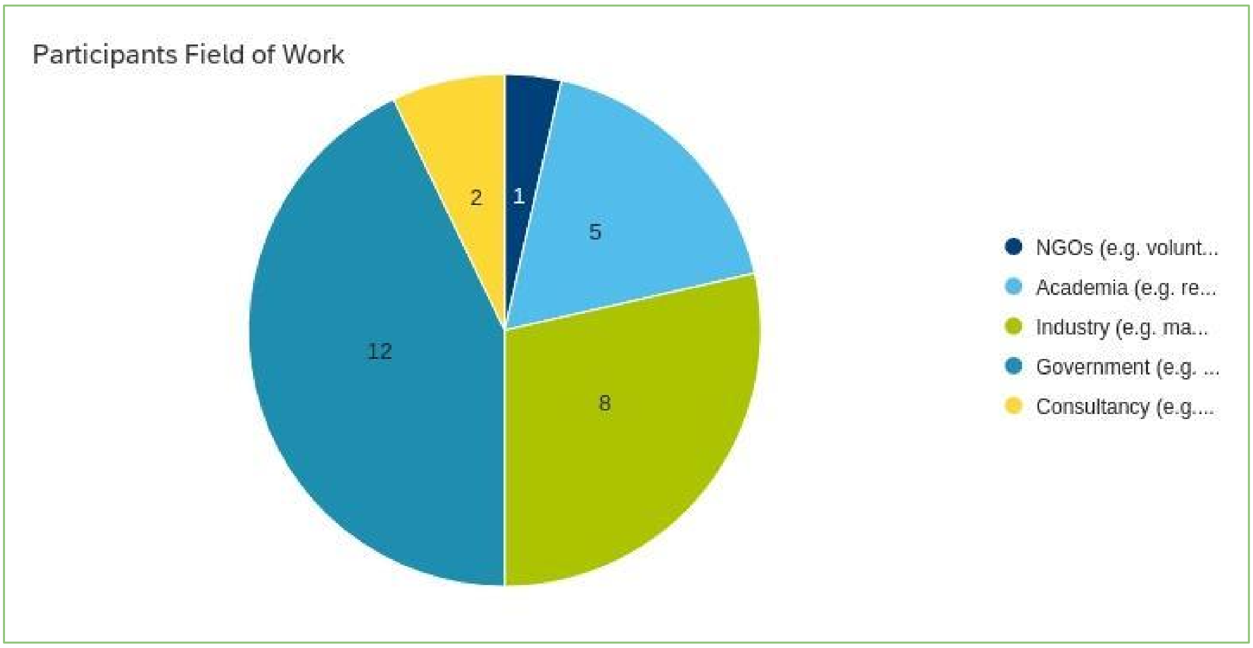

Figure 2Graph showing the field of work distribution among the survey participants. (Qualtrics, 2022).

As for the job position occupied by the experts they varied between Policy officers and advisors in governments and industries, Circular Economy facilitators and heads of offices, engineers and environmental sustainability engineers, managers, directors, and CEOs data analysts, as well as scientists, professors, and Ph.D. researchers.

When asked to self-assess their level of expertise in digital product passports and circular economy, 12 participants indicated having basic knowledge in these fields, 8 assessed themselves as having high expertise, and 1 as having a very high one. While on the other hand, 3 precise have a low one, and 4 have very low knowledge in the aforementioned topics. (Figure 3).

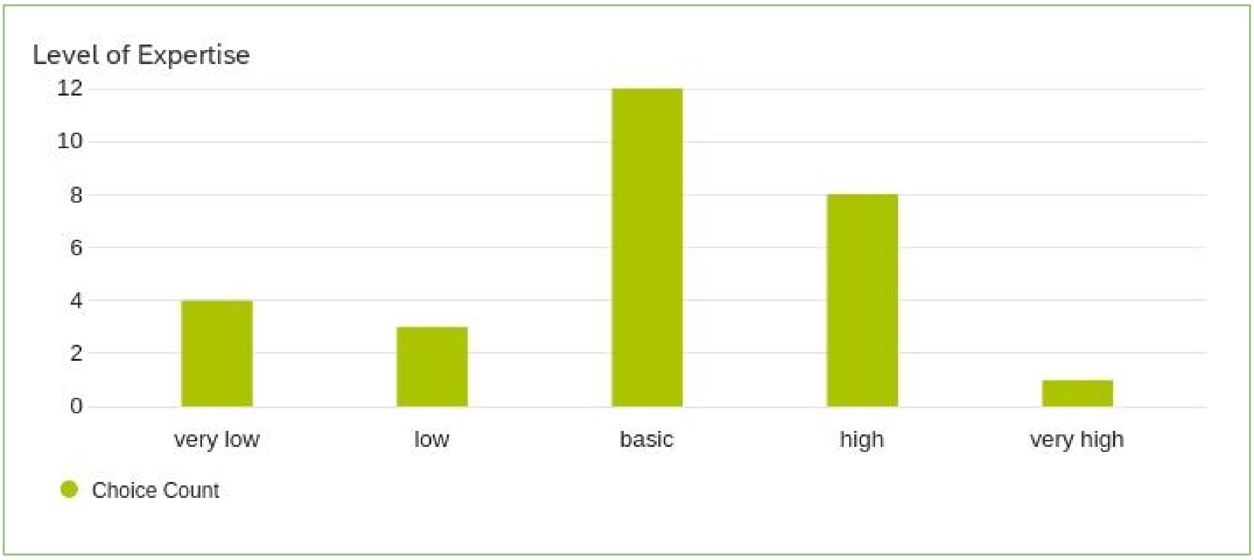

Figure 3Bar chart showing the self-assessment of the participants in regard to their expertise in the topics of digital product passports and circular economy. (Qualtrics, 2022).

B. First Delphi Round

As explained in the previous chapter about methods used, the Interquartile Range was calculated in order to determine around which value 50% of answers reside, for each question, and thus, later on, help to assess the consensus of experts for each question. (Annex 2)

To start, the first question is concerned with indicating which of the circular product strategies should be fostered by digital product passports in regard to electronic home appliances, where the participants were asked to choose at least one of the 10 R-strategies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover). Each strategy was coded by a number from 1 to 10 respectively, in order for the IQR calculation to be feasible. Repair was the R-strategies most chosen by the experts (33), followed by Remanufacture (26), Reuse (25), Recycle (25), and Repurpose (23). The R-strategies gaining the least votes were Refuse and Recover, with only 5 participants ticking each. The calculation of the IQR indicates a value of 4. This translates into having 50% of the data separated by or spread over 4 value points. The median for this question was equal to 6, indicating the central tendency response for this question (Table 1).

Refuse	Rethink	Reduce	Reuse	Repair	Refurbish	Remanufacture	Repurpose	Recycle	Recover
1	2	3	4	5	6	7	8	9	10
5	11	12	25	33	27	26	23	25	5

Table 1: Table showing the division of responses between the R-strategies for question 1 of the 1st Delphi survey. (Ayan, 2022)

From the second question to the eleventh, the same format was used to structure the questions. The 10 questions revolving around each of the 10 R-strategies, aim to assess how additional information from the product passport influence electric/electronic home appliances in will undergoing a certain R-strategy. The options of answers were diminished, slightly diminish, no influence, to slightly enhance, or enhance. These 5 options were then transformed to a 5-point Likert scale ranging from -2, -1, 0, 1, 2, to better be able to quantify the results and calculate the IQR.

For the question regarding how the additional information from product passports will influence the energy recovery from the incineration of electric home appliances (recover), most participants (21 out of 28) indicated that it would not influence the recovery of the appliances above (Figure 4 & Table 2). The calculated IQR was equal to 0 for this question, with a median equal to 3 (based on the fact that it is a 5-point scale).

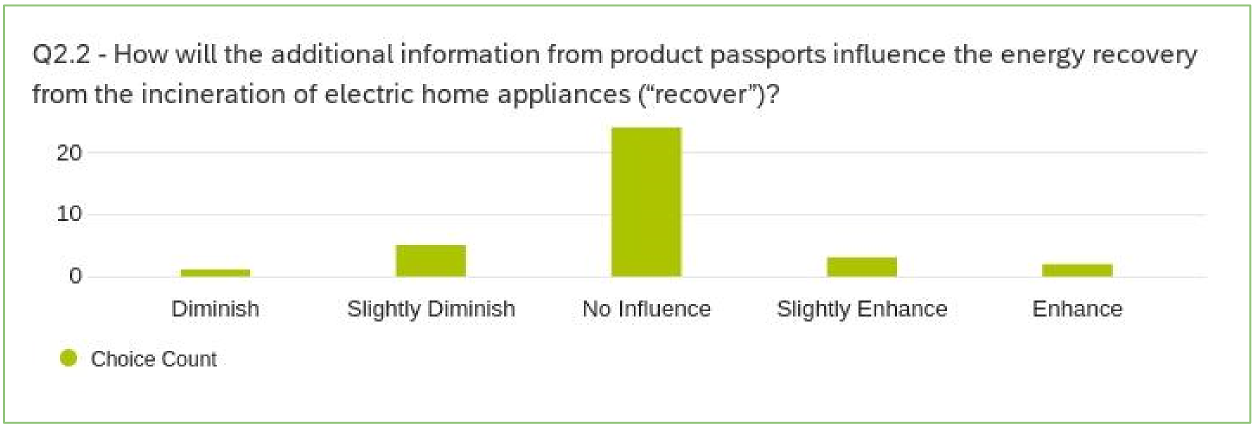

Figure 4: Bar chart showing the distribution of answers in the second question of the first round Delphi survey, related to Recovery. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	-1	0	1	2
1	5	21	3	2

Table 2 Table showing the distribution of answers for the second question of the 1st round survey, related to recovery, following the 5-point Likert scale. (Qualtrics, 2022).

The following question inquires about how the additional information from product passports will influence the use of parts of home appliances in a new product with the same purpose (remanufacturing). Most participants (18 out of 28) indicated that it would enhance remanufacturing of the above appliances, while 13 participants indicated that it would slightly enhance it (Figure 5 & Table 3). The calculated IQR was equal to 1 for this question, with a median equal to 5.

Figure 5 Bar chart showing the distribution of answers in the third question of the first round Delphi survey, related to Remanufacturing. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	-1	0	1	2
1	0	2	13	18

Table 3:Table showing the distribution of answers for the third question of the 1st round survey, related to remanufacturing, following the 5-point Likert scale. (Qualtrics, 2022).

The fourth question inquiries about how the additional information from product passports will influence the repair and maintenance of defective electric home appliances so they can be used with their original function (repair). All participants indicated that the DPP policy will either enhance (23 out of 28) or slightly enhance (9) the repairing of electric/electronic home appliances (Figure 6 & Table 4). The calculated IQR was equal to 1 for this question, and a median equal to 5.

Figure 6:Bar chart showing the distribution of answers in the fourth question of the first round Delphi survey, related to Repair. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	**-1**	**0**	**1**	**2**
0	0	0	9	23

Table 4:Table showing the distribution of answers for the fourth question of the 1st round survey, related to repaier, following the 5-point Likert scale. (Qualtrics, 2022).

The fifth question inquires about how the additional information from product passports will influence the use of discarded electric home appliances or their parts in a new product with a different function (repurpose). 17 participants indicated that the DPP policy will enhance the repairing of electric/electronic home appliances, while 10 indicated that it will slightly enhance the aforementioned, and 6 saw that ir would not influence it (Figure 7 & Table 5). The calculated IQR was equal to 1 as well for this question and the median of 5 also.

Figure 7:Bar chart showing the distribution of answers in the fifth question of the first round Delphi survey, related to Repurposing. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	-1	0	1	2
0	0	6	10	17

Table 5: Table showing the distribution of answers for the fifth question of the 1st round survey, related to repurposing, following the 5-point Likert scale. (Qualtrics, 2022).

As for the sixth question, inquiring about How will the additional information from product passports influence the reuse of discarded electric home appliances, that are still in good condition, in their original purpose by a different consumer (reuse). 11 participants indicated that the DPP policy will enhance the reuse of electric/electronic home appliances, while 17 indicated that it will slightly enhance the aforementioned, and 5 saw that it would not influence it (Figure 8 & Table 6). The calculated IQR was equal to 1 as well for this question, and the median equal to 4.

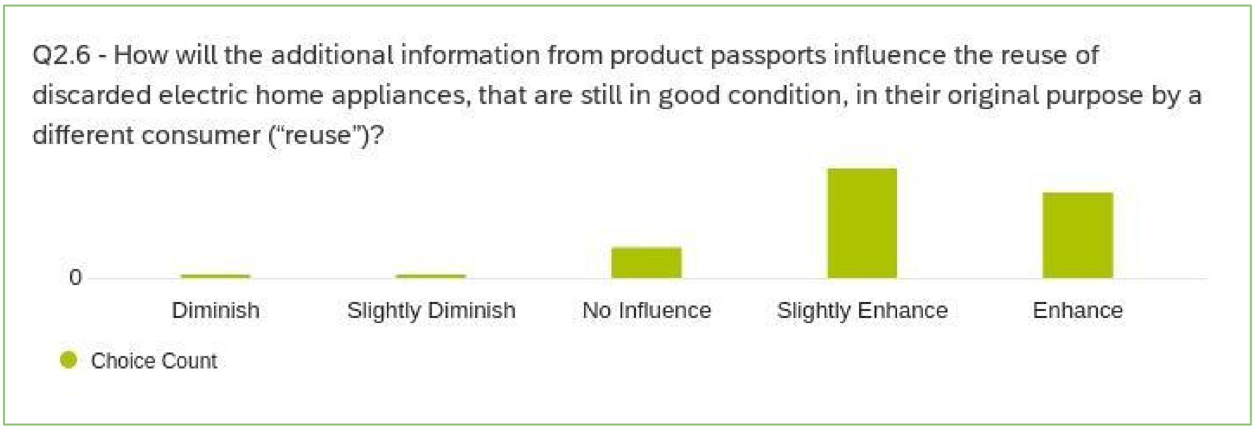

Figure 8:Bar chart showing the distribution of answers in the sixth question of the first round Delphi survey, related to Reuse. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	-1	0	1	2
0	0	5	17	11

Table 6:Table showing the distribution of answers for the sixth question of the 1st round survey, related to reuse, following the 5-point Likert scale. (Qualtrics, 2022).

The following question inquires about how the additional information from product passports will influence the restoration and update of old electric home appliances (refurbish). 19 participants indicated that the DPP policy will enhance the refurbishing of electric/electronic home appliances, while 10 indicated that it will slightly enhance the aforementioned, and 3 saw that it would not influence it (Figure 9 & Table 7). The calculated IQR was equal to 1 and the median to 5.

Figure 9:Bar chart showing the distribution of answers in the seventh question of the first round Delphi survey, related to refurbishing. (Qualtrics, 2022)

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	-1	0	1	2
0	0	3	10	19

Table 7:Table showing the distribution of answers for the seventh question of the 1st round survey, related to Refurbish, following the 5-point Likert scale. (Qualtrics, 2022).

Arriving at the 8th question, asking how the additional information from product passports will influence the intensity of usage of electric home appliances (rethink). The majority of the participants answered that the DPP will not have any influence of the Rethink R-strategy (19). 7 saw that it could slightly enhance, and 5 that it would enhance the above strategy. (Figure 10 & Table 8). The calculated IQR was equal to 1 and the median to 3.

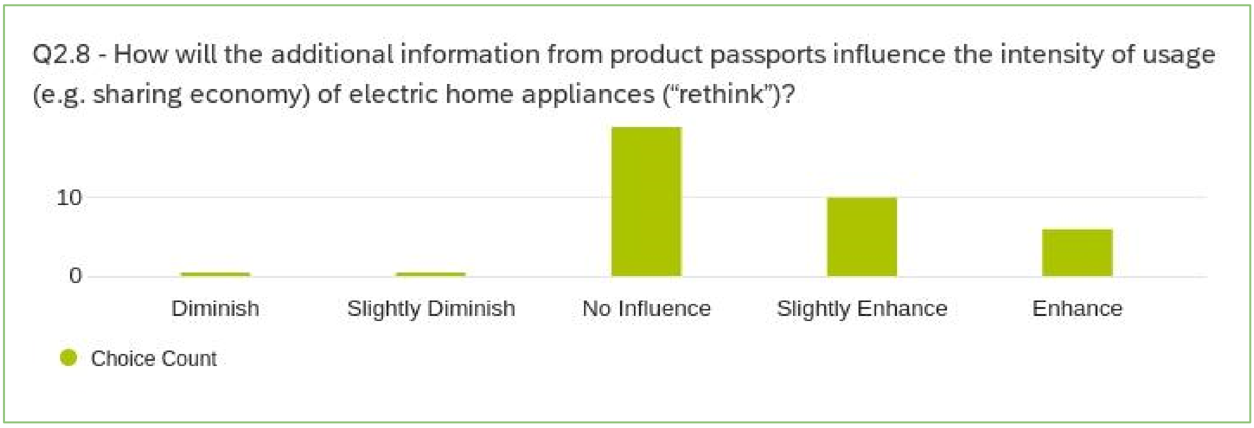

Figure 10:Bar chart showing the distribution of answers in the eighth question of the first round Delphi survey, related to rethinking. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	**-1**	**0**	**1**	**2**
0	0	19	7	5

Table 8:Table showing the distribution of answers for the eighth question of the 1st round survey, related to Rethinking, following the 5-point Likert scale. (Qualtrics, 2022).

The 9th question looks at how the additional information from product passports will influence the processing of materials of electric home appliances to obtain the same (higher or lower grade) quality (recycle). The majority of the participants (19) answered that the DPP will enhance the recycling of electric and electronic home appliances. 9 saw that it could slightly enhance, and 4 that it would not influence the above strategy. (Figure 11 & Table 9). The calculated IQR was equal to 1 and the median to 5.

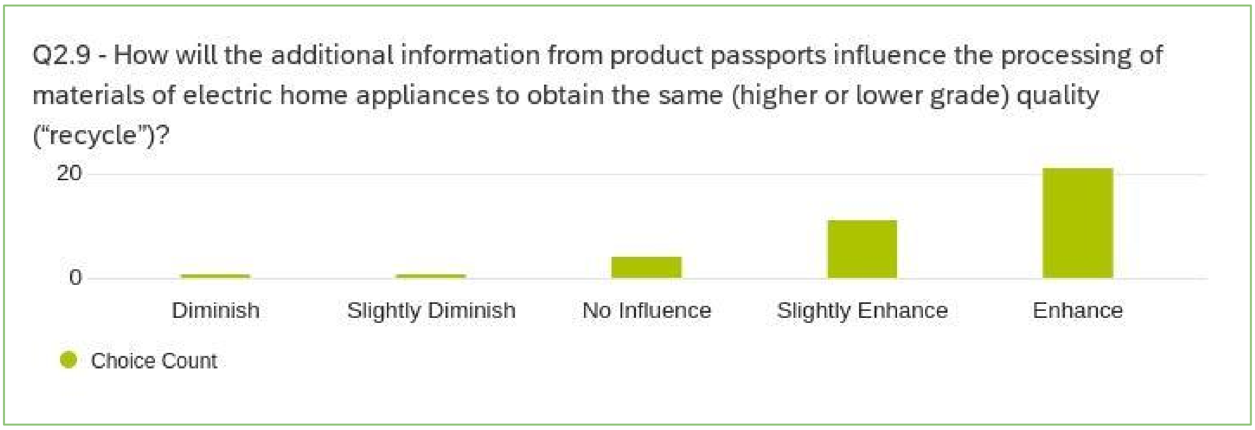

Figure 11:Bar chart showing the distribution of answers in the tenth question of the first round Delphi survey, related to recycling. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	**-1**	**0**	**1**	**2**
0	0	4	9	19

Table 9: Table showing the distribution of answers for the ninth question of the 1st round survey, related to recycling, following the 5-point Likert scale. (Qualtrics, 2022).

The following question inquires about how will the additional information from product passports influence the redundancy of electric home appliances ("refuse"). A big majority of the participants, 23 to be exact, found that additional information from product passports would not have any influence on refusal. 3 saw that ir could slightly enhance, while 4 chose that it would actually enhance it (Figure 12 & Table 10). The calculated IQR was equal to 0 for this question and the median to 3.

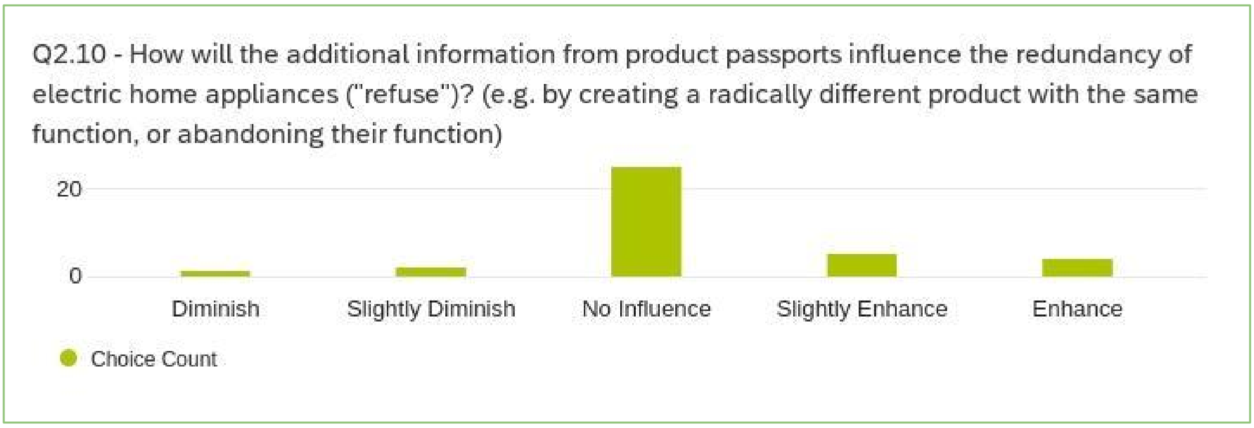

Figure 12: Bar chart showing the distribution of answers in the tenth question of the first round Delphi survey, related to refusal. (Qualtrics, 2022).

Diminish	Slightly Diminish	No Influence	Slightly Enhance	Enhance
-2	**-1**	**0**	**1**	**2**
0	2	23	3	4

Table 10:Table showing the distribution of answers for the tenth question of the 1st round survey, related to refusal, following the 5-point Likert scale. (Qualtrics, 2022).

Finally, the last question in this series, id about how the additional information from product passports will influence the consumption of natural resources and materials in the production of electric home appliances (reduce). The IQR for this question was equal to 1, since 4 experts indicated that the product passports could slightly diminish the above strategy, while 14 expressed that it would not influence it. Slightly enhancing, and enhancing the strategy through additional information about products, received 7 answers each. (Figure 13 & Table 11). The median for this question was equal to 3.

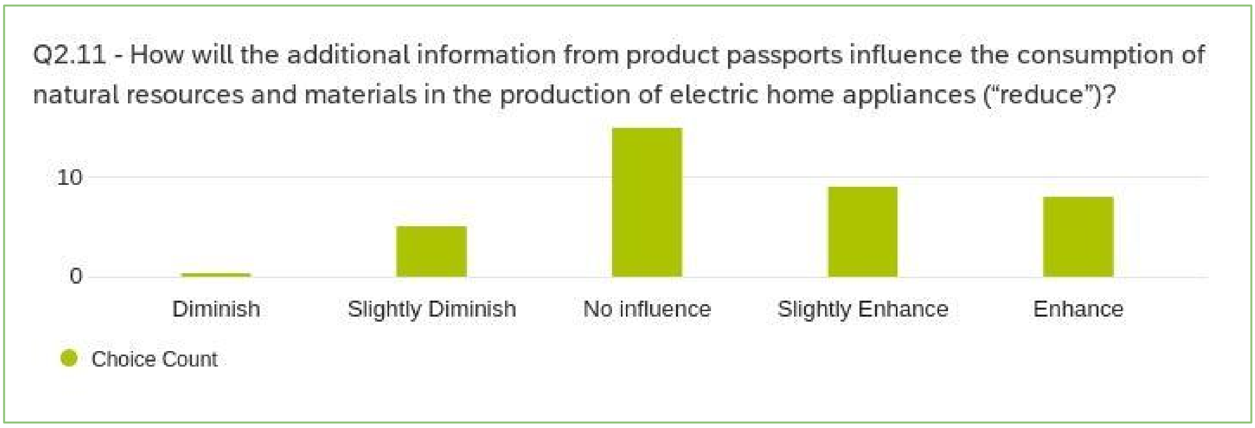

Figure 13:Bar chart showing the distribution of answers in the eleventh question of the first round Delphi survey, related to Reduce. (Qualtrics, 2022).

Diminish	Slightly Diminish	No influence	Slightly Enhance	Enhance
-2	-1	0	1	2
0	4	14	7	7

Table 11:Table showing the distribution of answers for the eleventh question of the 1st round survey, related to reduce, following the 5-point Likert scale. (Qualtrics, 2022).

The remaining questions of the 1st round were included for the means of quantification. Another series of similar questions, tied to the 10 R-strategies were asked and revolved around the estimation or prediction of the experts on how much of one electronic home appliance (in weight +/-%) will undergo a certain circular product strategy based on the additional information provided by product passports. When asked about Recovery, and how with the additional information from product passports, how much of a home appliance will be incinerated for energy recovery, the average of the answers accumulated to 8.15%, with an IQR of 10%. As for how with the additional information from product passports, how much of a home appliance will be processed to obtain materials of higher or lower grade ("recycle"), The average of the answers was 45.7 % with an IQR of 35.5%. With the additional information from product passports, the percentage presented by experts on how much of a discarded home appliance will be used in a new product with a different function (repurpose), the average of answers was 19.44%, with an IQR of 19%. Now for remanufacturing, the average percentage indicated by experts was 26.7, with an IQR of 13%. For refurbishing, the average percentage was 31.44% and an IQR of 34%. Concerning Repair, the average percentage accumulated to 41.35% with an IQR of 41.75%. The question about Reuse received an average of 26%, and an

IQR of 27.25%; while Rethink accumulated an average of 17.37, and an IQR of 19%. finally, when asked how many of all home appliances put on the market (in %) will become redundant by abandoning their functions or by offering the same functions with radically different products ("refused"), with the additional information from product passports, the average percentage of the answers was 7.45%, with an IQR of 10.5%.

The last set of questions revolved around how the price of spare parts of electric and electronic home appliances would be influenced by the presence of additional information through product passports, and how many how many percent (as in Â±%) will the price of spare parts of electric home appliances change. The first half of the question was assessed through a 5-point Likert scale, from diminish (-2), slightly diminish (-1), and no change (0), to slightly enhance (1) and enhance (2). 9 participants indicated that it will not have influence, while 8 saw that it could slightly decrease the price. Decrease and slightly increase got 4 participants each while increase was chosen by only one participant. The calculated IQR for this question was equal to 1. The second part of the question asked participants about the percentage of decrease or increase in the price of electric/electronic home appliances' spare parts. The values varied between -30% decrease, to 75% increase. The IQR for this question was equal to 30.25%. (Figure 14 & Table 12).

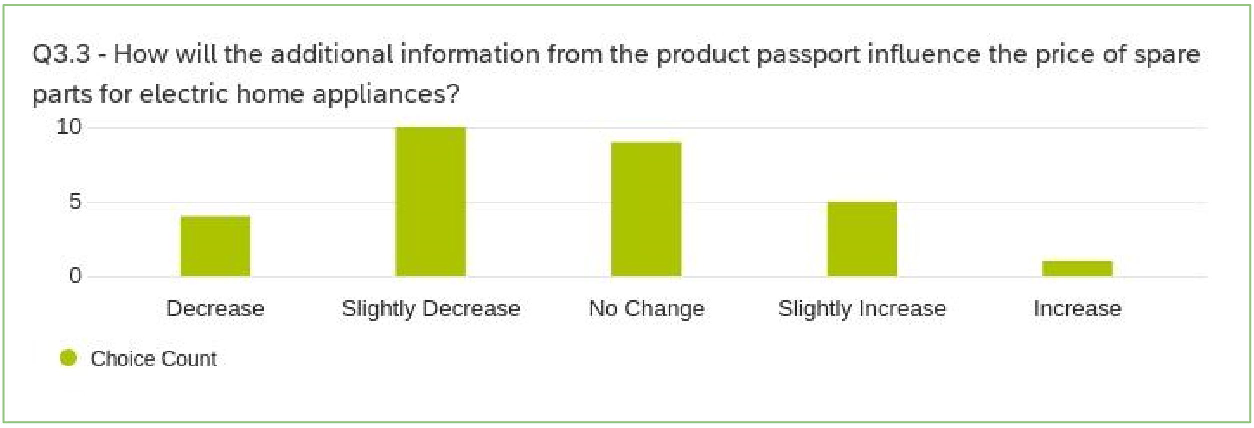

Figure 14:Bar chart showing the division of answers when participants were asked about the DPP influence over price of spare parts of electric and electronic home appliances.

Decrease	Slightly Decrease	No Change	Slightly Increase	Increase
-2	-1	0	1	2
4	8	9	4	1

Table 12:Table showing the division of answers when participants were asked about the DPP influence over price of spare parts of electric and electronic home appliances, following a 5-point Likert scale. (Qualtrics, 2022).

C. Second Delphi Round

For the Second round, and after analysis of the results of the first one, it was decided to reuse the same last two sets of questions related to the experts' estimation of influence and price change. This was due to the interest in studying how would their answers change, about the same question, if given the business-as-usual data and numbers at the beginning of the second survey, so that they could assess based on the current situation in electric and electronic home appliances and waste management. The difference between the rounds, is that fewer participants answered the second survey, as precised in the previous chapter. The experts in the second round accounted for 14 participants, who continued the survey in full.

Thus, the same series of questions, tied to the 10 R-strategies were asked, and revolved around the estimation or prediction of the experts on how much of one electronic home appliance (in weight +/-%) will undergo a certain circular product strategy based on the additional information provided by product passports, was included in the second round. When asked about Recovery, and how with the additional information from product passports, how much of a home appliance will be incinerated for energy recovery, the average of the answers accumulated to 16.5%, with an IQR of 8%. As for how with the additional information from product passports, how much of a home appliance will be processed to obtain materials of higher or lower grade ("recycle"), The average of the answers was 55.43 % with and IQR of 7%. With the additional information from product passports, the percentage presented by experts on how much of a discarded home appliance will be used in a new product with a different function (repurpose), the average of answers was 12.57%, with an IQR of 6%. Now for remanufacturing, the average percentage indicated by experts was 15.5%, with an IQR of 5%. For refurbishing, average percentage was 25.8% and an IQR of 7. Concerning Repair, the average percentage accumulated to 34.7% with an IQR of 9%. The question about Reuse received an average of 34.14%, and an IQR of 7%; while Rethink accumulated an average of 26.63%, and an IQR of 4%. finally, when asked how many how many of all home appliances put on market (in %) will be become redundant by abandoning their functions or by offering the same functions with radically different products ("refused"), with the additional information from product passports, the average percentage of the answers was 11.4%, with an IQR of 4%.

The last set of questions also revolved around how the price of spare parts of electric and electronic home appliances would be influenced by the presence of additional information through product passports, and how many how many percent (as in ±%) will the price of spare parts of electric home appliances change. The first half of the question was also assessed through a 5-point Likert scale, from diminish (-2), slightly diminish (-1), and no change (0), to slightly enhance (1) and enhance (2). 8 out of 14 participants indicated that it will not have influence, while 3 saw that it would slightly increase the price. Slightly decrease was chosen by 1 expert, while 2 saw that it would increase the price. The calculated IQR for this question was equal to 1 (Figure 15 & Table 13). The second half of the question asked participants about the percentage of decrease or increase in the price of electric/electronic home appliances' spare parts. The values varied between -30% decrease, to 25% increase. The IQR for this question was equal to 3%.

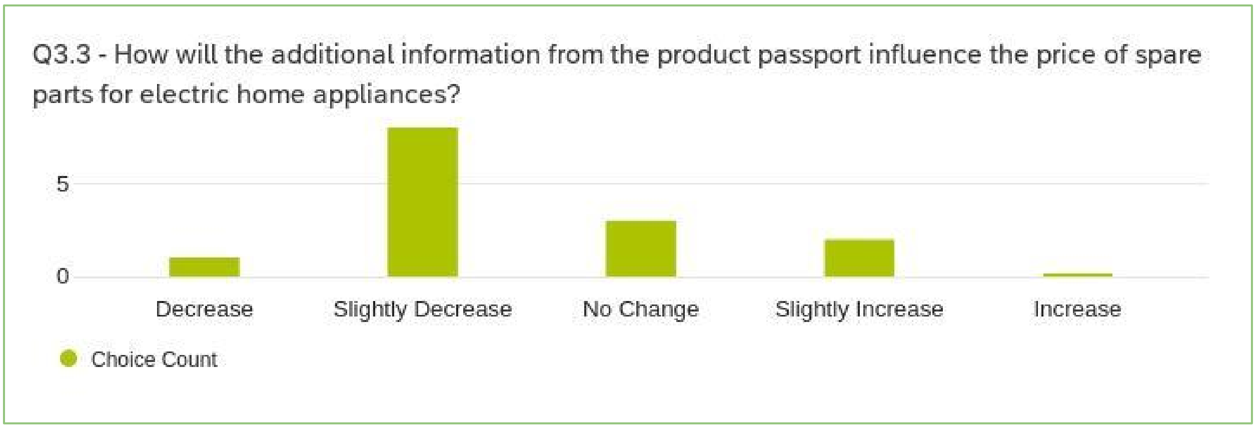

Figure 15: Bar chart showing the division of answers when participants were asked about the DPP influence over price of spare parts of electric and electronic home appliances, in the 2nd Delphi Survey round (Qualtrics, 2022).

Decrease	Slightly Decrease	No Change	Slightly Increase	Increase
-2	-1	0	1	2
0	1	8	3	2

Table 13:Table showing the division of answers when participants were asked about the DPP influence over price of spare parts of electric and electronic home appliances, following a 5-point Likert scale, in the 2nd Delphi Survey round (Qualtrics, 2022).

D. Inter-round Results

In order to analyze the sensitivity and stability of the rounds in comparison to each other, the median of each of the recurring questions (quantification questions) in both rounds was calculated. As explained previously in the methodology chapter, the lower and upper range were also calculated for each question, using the IQR and median values. The values are presented in Table 14 attached below. It thus become clear that the range between the upper and lower range for each question decreases from round 1 to round 2, for example, in question 8 (Q8) standing for "with the additional information from product passports, how many of all home appliances (in %) will be used more intensively, e.g., by sharing ("rethought")?", the range between the lower and upper in round one accounted for 23.5 %, while in the second round it was equal to 4%. (Table 14). As for question 9 (Q9) (Table 14), related to "with the additional information from product passports, how many of all home appliances put on market (in %) will be become redundant by abandoning their functions or by offering the same functions with radically different products ("refused")?"; the range between the lower and upper in round one accounted for 12.625%, while in the second round it was equal to 4%. (Table 14).

Rounds	*Metric*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Q9*	*Q10*
1st round	*IQR*	*10*	*35.5*	*19*	*13*	*34*	*41.75*	*27.25*	*19*	*10.25*	*30.25*
1st round	*Median*	*5*	*50*	*20*	*25*	*30*	*36.5*	*25*	*10*	*5.5*	*-2.5*
1st round	*1st Range*	*0*	*32.25*	*10.5*	*18.5*	*13*	*15.625*	*11.375*	*0.5*	*0.375*	*-17.625*
1st round	*2nd Range*	*12.5*	*60.5*	*29*	*25.5*	*49*	*60*	*39.75*	*24*	*13*	*29*
2nd round	*IQR*	*8*	*7*	*6*	*5*	*7*	*9*	*7*	*4*	*4*	*3*
2nd round	*Median*	*7.5*	*50*	*12.5*	*15.5*	*21.5*	*33*	*32.5*	*20*	*10*	*3.5*
2nd round	*1st Range*	*3.5*	*46.5*	*9.5*	*13*	*18*	*28.5*	*29*	*18*	*8*	*2*
2nd round	*2nd Range*	*11.5*	*53.5*	*15.5*	*18*	*25*	*37.5*	*36*	*22*	*12*	*5*

Table 14:Table showcasing the IQR, Median, Lower Range, & Upper Range calculations, for each of the concerned questions in both Delphi rounds. (Ayan,2022)

This decrease in range between the two Delphi rounds is illustrated by the graphs in Figure 15 where the median, 1st range, and 2nd Range values are plotted, and where it is apparent that the space between 1ST range line and the 2nd range line get smaller and decreases for every question from Delphi round 1 to Delphi round 2 (Figure 16). Figure 16 illustrates the IQR plot of the questions in the first and second round. For the same question, the IQR decreases in the second Delphi Survey, for example, for the fifth question, the IQR in the first round was of 35, and decreased to 7 in the second round. (Figure 17). These calculations and figures were needed to continue the sensitivity and stability analyses by helping in getting the R^2 and running the Wilcoxon Signed-Rank test.

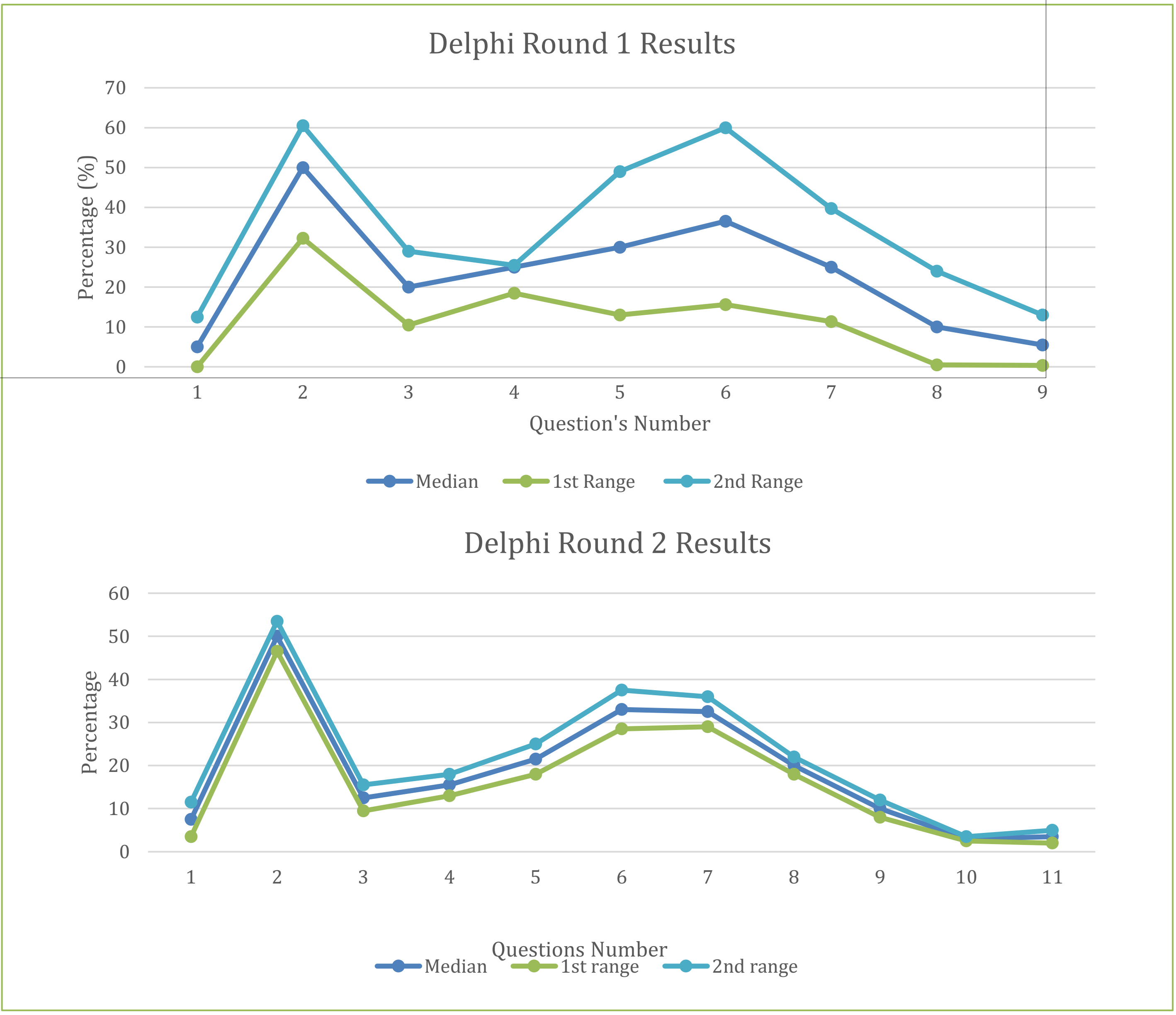

Figure 16:Graphs illustrating the difference between the two Delphi rounds, in terms of the Median, and the difference between the lower & upper ranges, for each question. (Ayan, 2022)

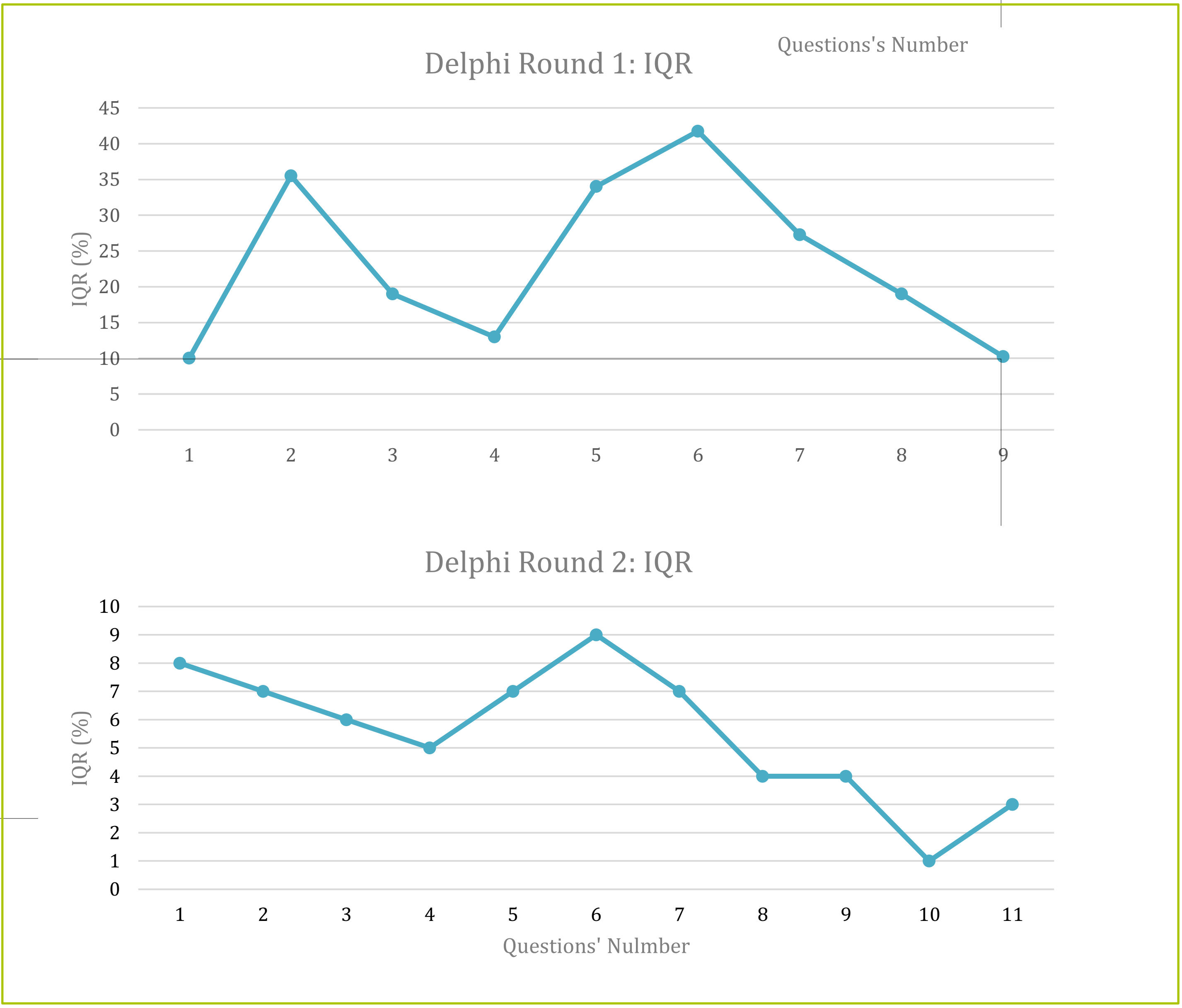

Figure 17: Graphs illustrating the difference between the two Delphi rounds, in terms of the calculated IQR, for each question. (Ayan, 2022)

V. Discussion

In order to analyze the meaning behind the aforementioned results, and conclude if there is consensus between the experts around the impact of additional information from the potential implementation of digital product passports in boosting the shift towards more circular product strategies; the sets of questions will be discussed such as the following: first Round Likert Scale questions analysis, inter-round quantification questions analysis, inter-round sensitivity analysis (on the quantification questions repeated between the first and second round), and an inter-round stability analysis. Limitations surrounding the research topic, the methodology and the analysis tools used will be elaborated upon as well.

A. Likert Scale Questions (1st Delphi Round)

To recapitulate, the Likert based questions of the first rounds were formulated around the 10 R-strategies with the goal of exploring how the additional information from product passports will influence the different strategies in regard to electric and electronic home appliances. With this set of questions, if the IQR ≤ 1 it signifies that the experts have come to a consensus around a specific answer. In this case, if IQR ≤ 1, given the median value (between 1 and 5: 1 for diminish, 2 slightly diminish, 3 for no influence, 4 for slightly enhance, and 5 for enhance) for the question, then the experts arrived at a consensus around how the additional information will influence each of the R-strategies. Thus, it will give the response, that 50% of the replies are tightly spread around. With this explanation, and the results for each question presented in the previous chapter, it was evident that a consensus was reached in regards of:

- Additional information from product passports will **not influence** the energy recovery from the incineration of electric home appliances.
- Additional information from product passports **slightly enhance/enhance** the use of parts of home appliances in a new product with the same purpose (remanufacturing).
- Additional information from product passports will **enhance** the repair and maintenance of defective electric home appliances so they can be used with their original function (repair).
- Additional information from product passports will **enhance** the use of discarded electric home appliances or their parts in a new product with a different function (repurpose).

- Additional information from product passports will **slightly enhance** the reuse of discarded electric home appliances, that are still in good condition, in their original purpose by a different consumer (reuse).
- Additional information from product passports will **enhance** the restoration and update of old electric home appliances (refurbish).
- Additional information from product passports will **not influence** the intensity of usage (e.g., sharing economy) of electric home appliances (rethink).
- Additional information from product passports will **increase** the processing of materials of electric home appliances to obtain the same (higher or lower grade) quality (recycle).
- additional information from product passports will **not influence** the redundancy of electric home appliances (refuse) (e.g., by creating a radically different product with the same function or abandoning their function).
- Additional information from product passports will **not influence** the consumption of natural resources and materials in the production of electric home appliances (reduce).

In summary, the experts agreed that digital product passports will not influence the recovery, rethinking, refusal, and reduction of electric and electronic home appliances, while they prospect that it will slightly enhance remanufacturing and reuse of the se appliances. They also agree that it will enhance repair, repurposing, refurbishing, and recycling of electric and electronic home appliances. 50% of the experts' opinion show a prediction that DPP policy will not diminish any of the R-strategies in regard to the same appliances.
Moreover 50% of the respondents agreed that "Repair" and "Refurbish" are the circular product strategies that should be fostered by digital product passports regarding electronic/electric home appliances. It was followed by "Refurbish" and "Remanufacture". The spread of the data (IQR=4) was very small for this question and the central tendency fell on Repair and Refurb ish.

B. Inter-round Quantification/ Prediction Questions

The questions that needed to be delved more deeply into, and were repeated in the second round, accounted for 11 questions, 10 percentage based, and 1 Likert Scale based. The 10 questions will be analyzed differently and separately then the Likert scale one. The first 9 questions are concerned with asking the experts to indicate according to their estimation how much of one electronic home appliance (in weight-%) will undergo a certain circular product strategy based on the additional information provided by product passports. The 10^{th} questions if with the additional information from the product passport, how many percent (as in ±%) will the price of spare parts of electric home appliances change.

In the first round, before providing the experts with the business-as-usual scenarios regarding these numbers, 50% of the responses had a significant spread of values for all the above-mentioned questions. This indicates a lower level of agreement, than with the Likert Scale questions, which prompted the decision to repeat these questions in the second round (Table 14). For example, the question regarding repair, where the average of replies predicts that 41.35% of home appliances put on market will be repaired, it has an IQR of 41.75% and a spread from 15.625% to 60%, meaning that 50% of replies span a range of 44.375%. Thus, even though based on the previous analyzed questions, repair will be enhanced by DPP in regard to electric/electronic home appliances, and the average of predicted repairs after DPP is 41.75%, it cannot be assumed that the experts have consensus about this prediction. As for the question regarding the change in price of spare parts of these appliances with DPP, 50% of the responses spanned a range of 46.625% (from -17.625% to 29%). The IQR was of 30.25%, which in comparison by the repair question (Q6) is lower, but since it spans a bigger range, it cannot be concluded that consensus is reached. (Table 14).

As for the second round, and after the provision of the current numbers in Europe, it is clear that the IQRs have significantly decreased as well as the range of 50% of the values, for each of the questions. The central tendency value was also more precise (Table 14). To mirror the examples given for the first round, the question regarding repair had a low IQR of 9% thus a small spread of between 28.5% and 37.5%, we can then conclude that the experts replying to the second round agreed that 33% of home appliances put on market will be repaired (Table 14). Following this logic, the second round thus brings in agreement the experts concerning the following:

- 7.5% of home appliances put on market will be recovered.
- 50% of home appliances put on market will be recycled.
- 12.5% of home appliances put on market will be repurposed.
- 15.5% of home appliances put on market will be remanufactured.
- 21.5% of home appliances put on market will be refurbished.
- 33% of home appliances put on market will be repaired.
- 32.5% of home appliances put on market will be reused.
- 20% of home appliances put on market will be rethought.
- 10% of home appliances put on market will be refused.

It can thus be predicted, according to the panel of experts that if DPP policy is to be implemented, electric and electronic home appliances will most likely be recycled, repaired, or reused.

Moreover, to go back to the Likert scale question common to both rounds, inquiring about how the additional information from the product passport will influence the price of spare parts for electric home appliances, in both rounds, experts agreed that it will most probably not change the price of spare parts of electric home appliances, since the IQR in both round was equal to 1, with a median of 3 (no change), and with minimal spread of 50% of opinions.

Following this, in the second round, the last question concerned with how many percent (as in ±%) will the price of spare parts of electric home appliances change with the additional information from the product passport, does not fully arrive to a consensus, with the central tendency value equal to 35% increase in the price.

Sensitivity Analysis

In order to study how does the experts' opinion change between the first round and the second round; a sensitivity analysis was first conducted. Thus, by biplotting the values of the IQR for each question (Figure 18), a rough approximation or prediction of what the results of the second round could be; this trend is thus used to see if a comparable difference exists between the rounds. Figure 17 showcases the trendline as well as its equation: $y = 0.0692x + 4.34$. The calculated coefficient of determination R^2 is equal to 0.1622, representing the linear regression and the proportion of variance between the rounds. Since in this case, R^2 is small and closer to 0, it can be interpreted that a significant difference exists between the first and second rounds. Thus, the results do not match between the rounds. Considering the equation of the graph (figure 18), the explanatory variable (here results of first round), are not correlated to the explained or dependent variable (results of the second round).

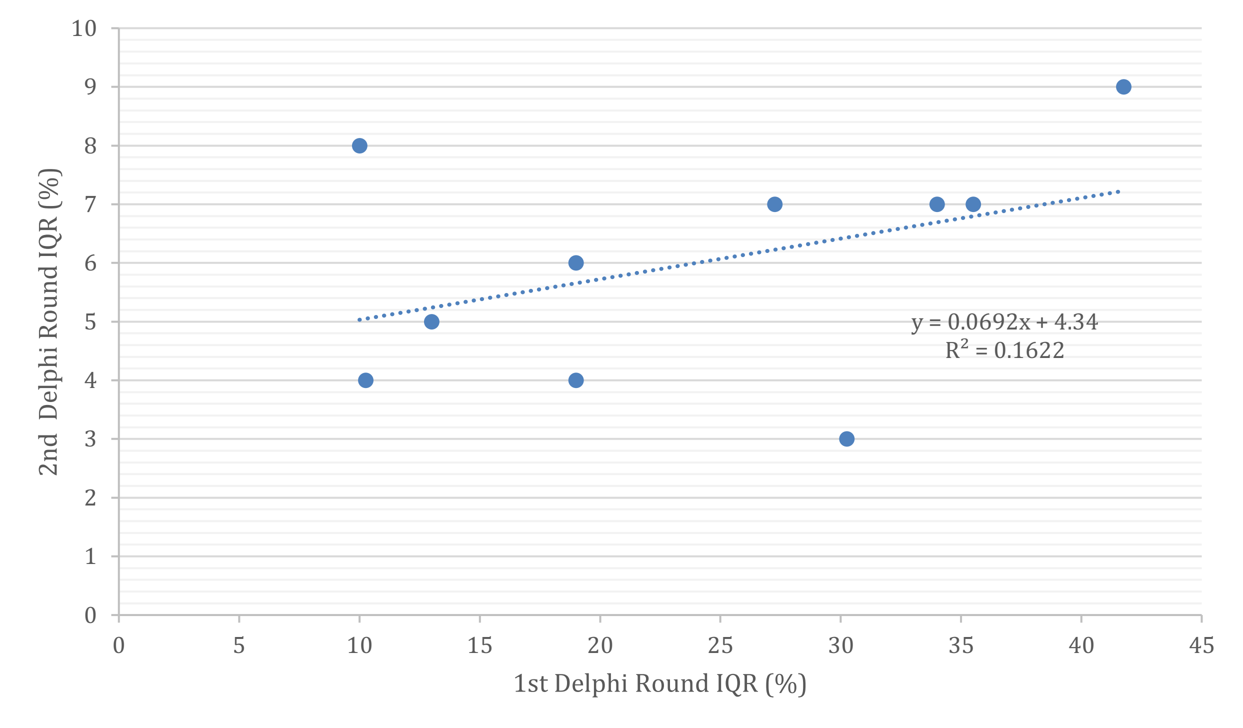

Figure 18:Biplot of the IQRs of both rounds, showing the equation and R^2 value. (Ayan, 2022)

To understand why a significant difference exists between the rounds, Figure 19, shows the significant decrease of IQR measurements of the 10 questions from round 1 to round 2 of the Delphi survey, showing the convergence of the IQRs in the second round, which signifies the convergence of the expert's opinions closer to each other after the 2nd round. (Figure 19). This significant decrease between the IQRs can be interpreted in favor of the business-as-usual scenarios given to the participants in the beginning of the 2nd round survey, hinting that they were insightful to the experts and helped them agree and predict more precise results. This also justifies the motivation behind repeating these predictive questions in the second round.

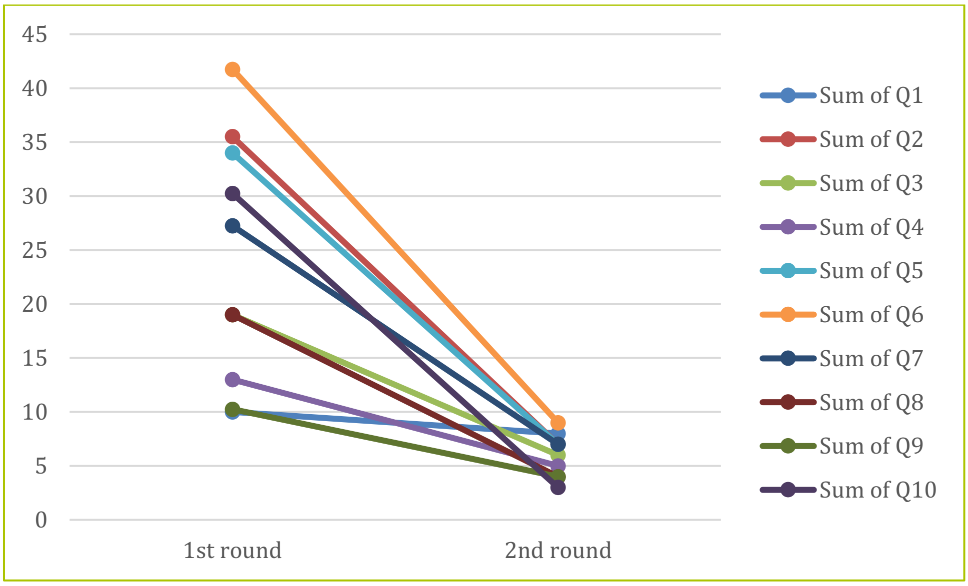

Figure 19:Graph illustrating the decrease of IQR between the two Delphi rounds. (Ayan, 2022)

Stability Analysis

Since the data retrieved does not fit a normal distribution, a stability test using the Wilcoxon Signed-Rank, where we consider for this analysis that the null hypothesis is H_0: the IQRs are equal between the 2 Delphi Rounds; and the alternative hypothesis H_A: the IQRs are not equal between the 2 Delphi Rounds. After the calculations needed (Table 15) for the test, the Test Statistic is obtained and is of 0, with a sample size of 10, and thus when compared to the correspondent Alpha Values (α) for n=10 (Table 16), the test statistic appears to be lower than all the alpha values 0 < 1 (for α=0.005) < 3 (for α=0.01) < 5 (for α=0.025) < 8 (for α=0.05) < 10 (for α=0.10). This shows a high significance, then we reject the null hypothesis H_0. The IQRs are thus not equal between the 2 Delphi rounds, meaning that a significant difference is indeed established which means that providing the experts with the current business-as-usual scenarios, regarding electric home appliances undergoing one of the r-strategies, appears to have been beneficial for building consensus and having significant results in the second round.

	Round 1 IQR	Round 2 IQR	DIFF	ABS DIFF	RANK OF ABS DIFF	Positive rank	Negative Rank
Q1	10	8	2	2	1	1	
Q2	35.5	7	28.5	28.5	9	9	
Q3	19	6	13	13	4	4	
Q4	13	5	8	8	3	3	
Q5	34	7	27	27	7	7	
Q6	41.75	9	32.75	32.75	10	10	
Q7	27.25	7	20.25	20.25	6	6	
Q8	10.25	4	6.25	6.25	2	2	
Q9	19	4	15	15	5	5	
Q10	30.25	3	27.25	27.25	8	8	
						Test Statistic	0
						Sample Size	10

Table 15:Table showing the calculations needed to run the Wilcoxon Signed-Rank test, through the difference between IQRs from both rounds, the absolute difference, ranking of the absolute difference, as well as the positive and negative ranks, in addition to the test statistic and sample size (Ayan, 2022)

	Alpha value				
n	0.005	0.01	0.025	0.05	0.10
5	-	-	-	-	0
6	-	-	-	0	2
7	-	-	0	2	3
8	-	0	2	3	5
9	0	1	3	5	8
10	1	3	5	8	10
11	3	5	8	10	13
12	5	7	10	13	17
13	7	9	13	17	21
14	9	12	17	21	25
15	12	15	20	25	30

Table 16: table showing the corresponding alpha value for each sample size for the Wilcoxon Signed-Rank Test (Statology, 2022)

Limitations

Some limitations can be deduced from this research paper, regarding the methodology used and analysis tools used. To be able to go through with researching the DPP policy potential in Europe, and due to the novelty of the topic, the methodology adopted was not implemented on a big sample scale. Most people working in the field of electronics have not heard about Digital Product Passport and thus won't be able to predict the consequences of its implementation. Experts working closely with the idea of product passports or similar policies were thus invited to participate, keeping the sample small, but varied to help assimilation of such policies in Europe. First limitation encountered, was through some feedback emails after the 1st and 2nd round emails were sent out, were some experts found the survey was too much based-on estimation, and two of them asked about the current numbers to create a better ides (which was implemented in round 2). Others asked for a definition of what these passports would include, so they could fill the survey include. Another limitation was due to the difference in the number of respondents between the two rounds, and the inconsistency of some in replying to all the questions of the surveys, it was hard to find the statistical tool best fitting to accommodate the aforementioned, since it did not fit a normal distribution. Thus, IQR was best suited to analyze the results of each round while allowing the comparison of results between the rounds through the sensitivity and stability analysis. Unrelated to methodology and analysis, the timing of the first survey was not fortunate and demanded a reminder to initiate participants to answer, since it was in the summer, and most Europeans were on summer holidays. The aforementioned delayed the acquisition of results.

VI. Conclusion

The potential implementation and implications of digital product passports on electronic and electric home appliances in terms of circularity improvement in Europe was evaluated through seeking opinions of experts in the fields of circular economy, electronics and policymaking. To study this, a quantitative study based on the Delphi method was conducted, composed of two complementary rounds to assess the consensus around this research question. IQR calculations were used to analyze the responses in both rounds. After running the first round and evaluating the agreement levels, some questions appeared to be needing further probing and exploration, thus a second round was established after providing the participants with needed business-as-usual numbers to set the current scene in Europe.

The results of the first round provided consensus about the questions formulated around the 10 R-strategies, with the goal of exploring how the additional information from product passports will influence the different strategies in regard to electric and electronic home appliances. The consensus fell around the following: (1) Additional information from product passports will **not influence** the recovery, the rethinking, the refusal and the reduction of electric and electronic home appliances; (2) Additional information from product passports will **slightly enhance** the remanufacturing and reuse of electric and electronic home appliances; (3) Additional information from product passports will **enhance** the repair, repurposing, refurbishment, and recycling of electric and electronic home appliances.

The second round tackled the questions where prediction and consensus were difficult, by providing some current numbers, mirroring as well the requests of participants on this matter, to better frame the predictive nature of this part of the survey. Results in the second round showed an increased consensus and more precise results. The aforementioned was assessed following a sensitivity (using the coefficient of determination) and stability analysis (using the Wilcoxon Signed-Rank test). The first test showed that a significant difference exists between the rounds, while illustrating the convergence of answers in the second round. While the second test, proved that the IQRs are not equal between the two Delphi rounds, meaning that providing the experts with the current business-as-usual scenarios, appears to have been beneficial for building consensus and having significant results in the second round. Consensus in the second round was around the following predictions: (1) 7.5% of home appliances put on market will be recovered; (2) 50% will be recycled; (3) 12.5% will be repurposed; (4) 15.5% will be remanufactured; (5) 21.5% will be refurbished; (6) 33% will be repaired; (7) 32.5% will be reused; (8) 20% will be rethought, and (9) 10% of home appliances put on the market will be refused. Finally, experts agreed that the implementation of DPP will most probably not change the price of spare parts of electric home appliances.

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VIII. Annexes

Annex 1: Table showing the list of companies and institutions contacted for the Delphi survey.

Government	Academia	Industry	NGOs
• Vlaanderen Circulair (Circular Flanders) • European Commission • Umweltbundesamt (Federal Environment Agency) • Walloon Government • Brussels Government • Belgian Federal Government • Ovam • City of Leuven • Platform Leuven Circulair • EWI • VLAIO • BBLV	• KU Leuven • VTT Technical Research Centre of Finland • TU Graz: Graz University of Technology • Université Paris 1 Panthéon Sorbonne	• BeWeee • Recupel • Herwin • Bebat • Denuo • DunavNET • Orgalim • Applia • Eurometaux • Back Market • iPoint-systems • WEEE-Forum • Teknologiateollisuus • ECOS • Netwerk Bewust Verbruik • Recupel • Repair Stichting International • Testaankoop • The Restart Project • VITO • IMEC	• Netwerk Bewust Verbruiken • Maakbaar Leuven • ECORES • Peer to Peer Foundation

		• Organic and Printed Electronics Association • Fnac Darty • Samsung • Apple • Miele • Haier/ Candy • LG • Bosh • Maakbaar Leuven • VITO • Agoria (Flemish Technology Federation) • Leuven Mindgate • SPIT • Barco	

Annex 2: List of question askes to the experts in the 1st Delphi round.

Question 1	In your opinion, please, indicate which of the circular product strategies should be fostered by digital product passports in regard to electronic home appliances? Please, tick at least one circular product strategy. Several choices are possible.
Question 2.1	How will the additional information from product passports influence the energy recovery from the incineration of electric home appliances ("recover")?
Question 2.2	How will the additional information from product passports influence the use of parts of home appliances in a new product with the same purpose ("remanufacturing")?
Question 2.3	How will the additional information from product passports influence the repair and maintenance of defective electric home appliances so they can be used with their original function ("repair")?
Question 2.4	How will the additional information from product passports influence the use of discarded electric home appliances or their parts in a new product with a different function ("repurpose")?
Question 2.5	How will the additional information from product passports influence the reuse of discarded electric home appliances, that are still in good condition, in their original purpose by a different consumer ("reuse")?
Question 2.6	How will the additional information from product passports influence the restoration and update of old electric home appliances ("refurbish")?

Question 2.7	How will the additional information from product passports influence the intensity of usage (e.g. sharing economy) of electric home appliances ("rethink")?
Question 2.8	How will the additional information from product passports influence the processing of materials of electric home appliances to obtain the same (higher or lower grade) quality ("recycle")?
Question 2.9	How will the additional information from product passports influence the redundancy of electric home appliances ("refuse")? (e.g. by creating a radically different product with the same function, or abandoning their function)
Question 2.10	How will the additional information from product passports influence the consumption of natural resources and materials in the production of electric home appliances ("reduce")?
Question 3.1	With the additional information from product passports, how much of a home appliance will be incinerated for energy recovery ("recover")?
Question 3.2	With the additional information from product passports, how much of a home appliance will be processed to obtain materials of higher or lower grade ("recycle")?
Question 3.3	With the additional information from product passports, how much of a discarded home appliance will be used in a new product with a different function ("repurpose")?
Question 3.4	With the additional information from product passports, how much of a home appliance will be used in a new product with the same purpose ("remanufacture")?

Question 3.5	With the additional information from product passports, how many of all home appliance put on market (in %) will be restored and updated (“refurbish”)?
Question 3.6	With the additional information from product passports, how many of all home appliances put on market (in %) will be repaired and maintained so they can be used with their original function (“repair”)?
Question 3.7	With the additional information from product passports, how many of all home appliances put on market (in %) will be reused in their same function by different consumers (“reuse”)?
Question 3.8	With the additional information from product passports, how many of all home appliances (in %) will be used more intensively, e.g., by sharing ("rethought")?
Question 3.9	With the additional information from product passports, how many of all home appliances put on market (in %) will be become redundant by abandoning their functions or by offering the same functions with radically different products ("refused")?
Question 4.1	How will the additional information from the product passport influence the price of spare parts for electric home appliances?
Question 4.2	With the additional information from the product passport, how many percent (as in ±%) will the price of spare parts of electric home appliances change? Please, enter a positive or negative integer without the "%" symbol.

Annex 3: List of question askes to the experts in the 2nd Delphi round.

Question 1.1	With the additional information from product passports, how much of a home appliance will be incinerated for energy recovery ("recover")?
Question 1.2	With the additional information from product passports, how much of a home appliance will be processed to obtain materials of higher or lower grade ("recycle")?
Question 1.3	With the additional information from product passports, how much of a discarded home appliance will be used in a new product with a different function ("repurpose")?
Question 1.4	With the additional information from product passports, how much of a home appliance will be used in a new product with the same purpose ("remanufacture")?
Question 1.5	With the additional information from product passports, how many of all home appliance put on market (in %) will be restored and updated ("refurbish")?
Question 1.6	With the additional information from product passports, how many of all home appliances put on market (in %) will be repaired and maintained so they can be used with their original function ("repair")?
Question 1.7	With the additional information from product passports, how many of all home appliances put on market (in %) will be reused in their same function by different consumers ("reuse")?
Question 1.8	With the additional information from product passports, how many of all home appliances (in

	%) will be used more intensively, e.g., by sharing ("rethought")?
Question 1.9	With the additional information from product passports, how many of all home appliances put on market (in %) will be become redundant by abandoning their functions or by offering the same functions with radically different products ("refused")?
Question 2.1	How will the additional information from the product passport influence the price of spare parts for electric home appliances?
Question 2.2	With the additional information from the product passport, how many percent (as in ±%) will the price of spare parts of electric home appliances change? Please, enter a positive or negative integer without the "%" symbol.

Annex 4: Table showing the corresponding number for each alpha value in relation to the sample size n.

	Alpha value				
n	**0.005**	**0.01**	**0.025**	**0.05**	**0.10**
5	-	-	-	-	0
6	-	-	-	0	2
7	-	-	0	2	3
8	-	0	2	3	5
9	0	1	3	5	8
10	1	3	5	8	10
11	3	5	8	10	13
12	5	7	10	13	17
13	7	9	13	17	21
14	9	12	17	21	25
15	12	15	20	25	30
16	15	19	25	29	35
17	19	23	29	34	41
18	23	27	34	40	47
19	27	32	39	46	53
20	32	37	45	52	60
21	37	42	51	58	67
22	42	48	57	65	75
23	48	54	64	73	83
24	54	61	72	81	91
25	60	68	79	89	100
26	67	75	87	98	110
27	74	83	96	107	119
28	82	91	105	116	130
29	90	100	114	126	140
30	98	109	124	137	151