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Towards Circular Economy in the Household Appliance Industry: An Overview of Cases

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Received: 30 June 2020; Accepted: 1 November 2020; Published: 3 November 2020

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Abstract: Circular Economy is a means to ensure sustainable production and consumption patterns. However, it is still at an embryonic stage of implementation in manufacturing companies. Given its potential, the household appliance industry is a promising arena for the adoption of Circular Economy. Thus, this study aims to investigate and systematize how Circular Economy has been adopted in the household appliance industry, through a multiple case study research. Twenty cases are analyzed following a Research Framework, to map: (i) the Circular Economy 4R strategies of reduce, reuse, remanufacture and recycle; (ii) the Circular Economy levers, i.e., whether circular product design practices, servitized business models or supply chain management actions are undertaken; (iii) the role of digital 4.0 technologies as enablers; (iv) the benefits achieved. The analysis showed that servitized business models and supply chain management actions are widely used levers, while little attention is devoted to circular product design practices. Internet of Things (IoT), Big Data and Cloud emerged as powerful enablers of servitized business models. Two main patterns of Circular Economy adoption in the household appliance industry emerged from cases: incremental and radical adoption patterns. Incremental adoption patterns are based on design strategies focused on reduce and recycle, mainly led by manufacturers. Radical adoption patterns are instead focused on disruptive practices based on reuse, remanufacture, servitization and sharing, where digital 4.0 technologies serve as enablers. Overall, this exploratory research lays the foundation for a stronger and more systemic understanding of the adoption of Circular Economy in the household appliance industry.

Keywords: circular economy; household appliances; case studies; sustainable development; reduce; reuse; remanufacture; recycle; circular benefits

1. Introduction

Circular Economy (CE) recently emerged as a new sustainable paradigm to address resource scarcity and climate change [1]. By decoupling economic growth from resource exploitation, CE has been conceptualized as an alternative to the current linear economy, which is based on a 'take-make-dispose' scheme [2]. CE strategies include the implementation of closed-loop supply systems based on activities such as reusing, remanufacturing and recycling, the sale of the function rather than the product in itself and business approaches characterized by collaboration and sharing [3,4]. In a CE, the value is not related to the increasing of sales and the flows of materials, but to the ability of using resources in multiple cycles and reducing waste by narrowing, slowing or closing the loop [5,6]. However, CE is still at an embryonic stage of implementation in manufacturing companies [7–9], and several challenges should be overcome to redesign industries and supply chains for the CE [4].

The household appliance industry is a promising arena for studying the adoption of CE, given its high potential as well as its environmental impact [10]. In fact, household appliances such as washing machines, fridges and dishwashers stress the environment throughout their whole lifecycle.

To produce them, the European industry uses every year about 500 kt of steel, 200 kt of plastics, 60 kt of copper and 40 kt of aluminum; during usage, the total energy and water EU consumption sums up to 25 TWh and almost 2 km^3 of water per year; at the end of life, only 35% of appliances are collected and recycled in the EU each year [11].

Despite this potential, previous literature investigated CE in the household appliance industry in a scattered way in terms of strategies, levers, enablers and benefits. Most of the literature investigated reuse and recycle strategies, but without considering the required change in business models and product design. For instance, Curran and Williams investigated the role of reuse organizations in Wales and England, discovering that these practices are hampered by the current waste management system based on quantities instead of social value generated [12]. Kissling et al. identified barriers and success factors for several business models focused on the reuse of household appliances, highlighting a lack of legislation and the difficulty of accessing sufficient volumes of good used appliances as the most impactful barriers [13]. Truttmann and Rechberger approached the reuse of household appliances as an effective means to extend their lifespan, highlighting the trade-off between energy consumption during usage and resource conservation in manufacturing phase [14]. Finally, Franco analyzed the CE effects of combining product design and servitized business model strategies for closing the loop through system dynamics simulation modelling, applying the model also to the household appliance category [15]. Another large share of literature focused on the role of citizens and governments in enabling sustainable patterns, but wit hout linking them to CE systemic strategies. For instance, Abeliotis et al. analyzed the attitudes and factors affecting Cypriots' preferences regarding the ownership of household appliances, such as age, gender and income [16]. Hennies and Stamminger empirically investigated the effects of obsolescence on household appliance in Germany [17]. Lieder et al. used washing machines as a case study to assess customer preferences and empirically explore the opportunities of CE in the city of Stockholm, discovering a general interest in access to washing services rather than owning washing machines [18]. Kelly reviewed existing policy measures and instruments to identify their effectiveness in relation to appliances residential energy consumption [19]. Lastly, previous literature focused on the assessment of the impacts of CE in the household appliance industry, even though economic, environmental, and social benefits have been seldom investigated together. For instance, Parajuly and Wenzel quantified the economic potential of CE in reusing and recycling household Waste from Electrical and Electronic Equipment (WEEE) [20]. Morioka et al. evaluated the eco-efficiency of a closed-loop scheme for household appliances, based on life-cycle assessment and material flow analysis, and found that increasing product life through remanufacturing is more convenient than the traditional option of substitution and recycling [21] Pini et al. compared the environmental performances of preparation for reuse activities for electronics and household appliances, with cost externalities and job potential creation [22].

Thus far, literature lacked a systemic analysis and systematization of current CE practices in the household appliance industry [10]. In fact, CE strategies have been seldom investigated in combination. CE levers and enablers as product redesign, servitization, reverse logistics and digitalization have been investigated by the literature, but rarely has their intersection been addressed. The same holds for circular benefits: few contributions addressed all the kind of benefits—economic, environmental and social—simultaneously. In addition, extant literature is still generic in the context of manufacturing companies, lacking a sector-specific approach for the implementation of CE, as in the case of the household appliance industry [9].

To fill these gaps, the aim of this study is to systematize how CE is adopted by the household appliance industry by the means of multiple case studies.

The remainder of the paper is organized as follows. Section 2 presents the methodology adopted for the research. In Section 3, each case is presented and described. Section 4 discusses the findings. Lastly, conclusions, managerial implications and limitations are drafted in Section 5.

2. Methodology

This research is exploratory in nature, since it investigates a topic that has not been thoroughly investigated in the past, i.e., the systemic analysis and systematization of CE practices in the household appliance industry. Exploratory research is usually conducted to achieve a better understanding of existing problems, but results are usually qualitative and often open-ended. Exploratory research is often carried out in applied product and market research, especially in the case of data limitations. Methods adopted in exploratory research are split into primary and secondary research methods. In primary research methods, data are collected by researchers directly from the subject of investigation (such as a group of people, a company, etc.) through surveys and interviews. On the other hand, secondary research methods use existing data and resources (such as articles, papers, etc.) about the subject of the study.

This exploratory research develops a Research Framework to analyze and classify CE cases in the household appliance industry, and to highlight patterns of CE adoption.

The research process is composed of three steps: (i) background analysis; (ii) Research Framework development; and (iii) multiple case study. First, a background analysis is carried out, to highlight existing research frameworks that have already been used to analyze and classify CE cases, as well as to highlight the most relevant elements from the CE theory in terms of strategies, enablers, levers and benefits (Section 2.1). Then, the Research Framework to analyze and classify CE cases in the household appliance industry is developed (Section 2.2), based on the most relevant elements from the background analysis. Lastly, multiple case studies in the household appliance industry are carried out (Section 2.3).

2.1. Background Analsyis: Circular Economy Frameworks and Main Elements

2.1.1. Circular Economy Frameworks

Several Research Frameworks have been used in the past to analyze CE cases. Diaz Lopez et al. [23] analyzed 143 secondary cases focusing on the implementation of resource-efficiency measures in various industries. They classified the cases and the measures in a framework distinguishing five business model components, i.e., supply chain, internal processes, customer interface, financial model and value proposition. Lüdeke-Freund et al. [5] reviewed 37 CE business models found in literature, in order to define how companies create value in the journey towards CE. These business model patterns have been reviewed through a morphological analysis, by means of a framework built on the general business model dimensions of value proposition, value delivery, value creation and value capture. Ingemarsdotter et al. [24] analyzed 40 secondary cases taken from practice, to explore how Internet of Things (IoT) contributes to the transition towards CE. They mapped the cases through a purposely developed framework, which combines the IoT capabilities of tracking, monitoring, control, optimize and design evolution with the circular strategies of increase efficiency, increase utilization, extend product life, reuse, remanufacturing and recycling. Kalmykova et al. [25] analyzed 100 secondary CE implementation cases, and categorized them in a framework that has been built as a combination of the scope of the project (from single materials, single products to the entire sectors and systems), the part of the value chain involved (from materials sourcing to design, manufacturing, distribution, use and end of life) as well as the implementation levels (from strategic planning to research and development, pilot scale, market ready). Guzzo et al. [26] reviewed 45 secondary cases to develop a circular innovation framework, which contains circular strategies to facilitate the adoption of product-, use- and result-oriented product-service system business models.

2.1.2. Main Circular Economy Elements

According to the CE literature, four main 'R' strategies should be pursued in the household appliance industry to achieve CE. They are reduce, reuse, remanufacture and recycle [10]. An organization follows the reduce strategy when it improves resource efficiency. In this way, the organization causes a reduction in the flow of goods produced or a reduction in waste and energy consumption. The reuse and remanufacture strategies imply a second-hand market and the recovery of the products at their end-of-use stage. While reuse involves repair activities to recirculate products, remanufacture requires more processes and often disassembling activities to recirculate parts and components [27]. Lastly, recycle focuses on recirculate materials by processing waste and discarded products to obtain secondary raw materials. The product must be demolished and loses the added value achieved in the manufacturing phases.

CE literature recognizes three levers on which companies and organizations may act to implement CE and pursue the 4R strategies [4], i.e., whether Circular product design practices [6], Servitized business models options [28] or Supply Chain management actions are undertaken [29]. Circular product design maintains the value of products for as long as possible by narrowing, slowing or closing the resource loops [6]. These practices allow the use of fewer or recycled materials, the extension of the product life and the enhancement of multiple lifecycles. Examples of circular design practices are material selection, design for sustainable behavior, design for attachment and trust, durability, standardization and modularity, design for disassembly or reassembly. Servitized business models change the relationship between companies and customers, facilitating contracts that sell the functional access rather than the product [30,31]. Servitized business models can be e.g., after-sales services, such as maintenance and repair, leasing and pay-per-use contracts, and sharing activities. There are three types of servitized business model: product-oriented, use-oriented, and result-oriented [28]. They advance the concept of selling the use or the function of a product and not only the product itself [32]. Lastly, supply chain management aims to integrate the actors along the entire supply chain and induces cooperation to facilitate the transition to CE [29]. Multi-echelon supply chains involve the flow of products between different actors comprising of manufacturers, distributors, retailers and customers. Given the structure and the complexity of linear, multi-echelon supply chains, great economic benefits can be achieved by minimizing transportation, inventory and operational costs in forward logistics [33]. Moreover, stronger collaboration simplifies recovery activities. A close relationship between companies and customers is needed for introducing a servitized business model. For achieving the desired sustainability performance, information sharing among manufacturers and logistics service providers is crucial [34]. Therefore, supply chain management for CE includes cooperation activities and the implementation of a reverse logistic. The latter refers to a closed-loop system that takes place when a company manages to recover its waste.

The implementation of the three levers can be enabled by digital 4.0 technologies [32]. Internet of Things (IoT) technology refers to sensors applied to mechanical appliances or electronic equipment and gives information on conditions and functioning of the products [24,32,35,36]. Big Data and Analytics allow revising data collected by IoT to improve decision-making processes and prevention systems [32]. Cloud platforms are software that allow sharing data or multimedia materials, to enhance the offer of services rather than products and the rise of the platform economy [37]. Three-dimensional (3D) printing allows realizing 3D objects starting from a computer model through additive manufacturing [38].

Lastly, CE may lead to economic, environmental or social benefits [39–41]. Environmental benefits are related to the impact of industrial processes on the stability of the ecosystem, for example, the reduction of greenhouse gas emission or the reduction of energy and resources consumption. Economic benefits are split into economic benefits for customers and economic benefits for the supply chain. Customers may have a financial advantage when savings may be achieved in the usage phase thanks to more energy-efficient products. The supply chain may profit from CE by paying less in materials, and by saving on dismantling and landfill costs. Additionally, the offer of innovative or more sustainable products can increase the brand image and the competitiveness of the supply chain, as well as the compliance to legal frameworks as carbon tax-based ones. Social benefits happen when CE brings net gains to society, as in the case of growing employment opportunities, increasing job quality and promoting equity.

2.2. Research Framework

Our Research Framework brings together the strategies, the levers, the enablers and the benefits of CE in the household appliance industry that emerged from the background analysis. The Framework adds to current already developed CE frameworks since it promotes a systemic vision of CE implementation, and because it highlights a logical path for the implementation of the CE. This logical path:

1. Starts from answering 'how' CE can be implemented, i.e., through which strategy of reduce, reuse, remanufacture or recycle (CE 4R scheme pursued);
2. Then, it provides an answer to 'what' each case is doing, i.e., what levers (among circular product design; servitized business models options or supply chain management actions) and enablers (among the enabling digital technologies) are activated by the company;
3. Finally, it answers 'why' the initiative has been run, i.e., to gather what kind of benefits, among environmental benefits, social benefits and economic benefits for users or for the supply chains.

The Framework is shown in Figure 1. According to the framework: at least one R strategy should be pursued to implement CE; to pursue them, companies may act on the three CE levers, which can be enabled by digital 4.0 technologies; finally, sustainability benefits are achieved. The combination of these aspects and their joint application to the household appliance industry was overlooked by previous research analyzing CE practices.

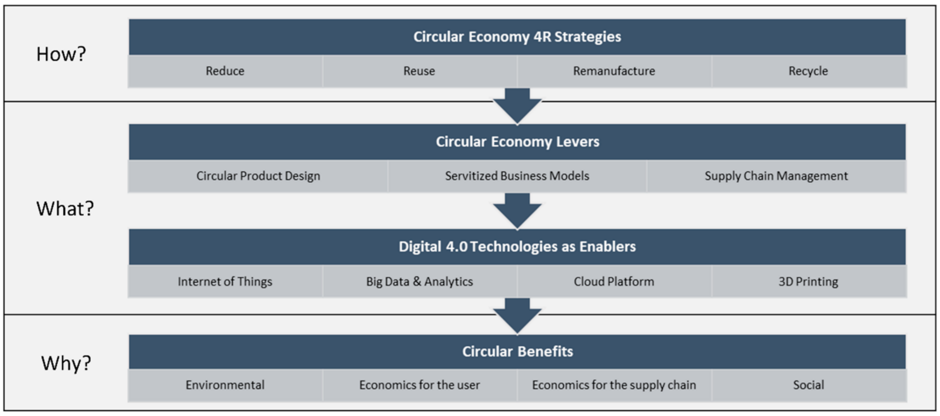

Figure 1. The Research Framework.

2.3. Multiple Case Study Analysis

To systematize how CE is adopted in the household appliance industry, a multiple case study methodology was adopted [42]. Due to the exploratory purpose of the research, multiple case study constitutes a suitable methodology. Case study is a methodological approach that involves the in-depth exploration of a specific, bounded case, using multiple forms of data collection. The strength of case studies is to allow the study of a phenomena in their context, thus conceding the adoption of a systemic perspective over the different configurations and different areas addressed by the study. Consequently, case study research allows for a richer knowledge of the system under study. Multiple case study is a case research where more than one company study is carried out.

The Research Framework of Section 2.2 guided the case studies and was used to depict the results. Both primary (data collected by researchers directly from the subject of investigation) and secondary (use of existing data and resources about the subject of the study) case studies have been carried out. Companies were selected according to a judgmental sampling technique. Each case company: (i) focuses on household appliances; and (ii) has undertaken projects to achieve CE. In total, 20 cases are analyzed.

For primary cases, semi-structured interviews were carried out. For each interview, specific guidelines were drafted following the Research Framework, to outline the topics investigated and the questions asked. Each interview lasted 2 h, and different company roles were consulted. Interview scripts were transcribed, coded and validated with respondents. To enhance validity, triangulation with secondary sources has been carried out. A total of four primary cases have been analyzed.

Secondary cases were selected from technical reports of public and private organizations focused on CE. Information was taken directly from the company website and from newspaper articles. A total of 16 secondary cases have been analyzed.

Lastly, data analysis has been carried out, both within- and cross-cases. To draft observations, we employed a frequency and an occurrence analysis as statistics techniques [26]. Given the early stage of research in CE, we opted for making mere counts rather than adopting advanced statistical techniques to analyze patterns. Data were used to systematize how CE is adopted by the household appliance industry, by defining patterns of CE adoption.

3. Case Studies

3.1. Primary Cases

3.1.1. Astelav (Ri-Generation)

Astelav is an Italian company, founded in 1963 and located in Turin, which manages the supply of spare parts for household appliances. The group employs 60 people and in 2018 recorded sales of 13 million euros. In 2017 Astelav, together with SERMIG (SERvizio MIssionario Giovani, a charity association) started the Ri-Generation project, aiming at recovering and selling back household appliances such as washing machines, dishwashers and tumble dryers that have reached the end of life. These products, which would otherwise be disposed of, are collected by the company directly from costumers or through logistic centers, to be sold back in one of the Astelav distribution centers or through the online website. Moreover, the company does not just sell recovered products but supports costumers during the entire usage phase, by offering technical assistance services at a discounted price. The Ri-Generation project can lead to several benefits, both for the customer and the supply chain. Customers can save money buying recovered appliances of which the price is lower than that of new ones. On the supply chain side, this initiative allows to decrease costs of disposal and the need for new materials. The Ri-Generation initiative also generates social benefits, since refurbishment is more labor-intensive than direct manufacturing. SERMIG, the charity association, collaborates with Astelav by providing people in social or economic difficulty, that can be employed as workers. On the environment side, Ri-Generation reduces waste production avoiding appliances from being landfilled or exported. During the first year of the project, Astelav recovered more than 1000 washing machines, saving 23,000 kg of concrete, 23,000 kg of steel, 11,000 kg of plastic materials and 3000 kg of aluminum (https://corporate.enel.it/content/dam/enel-it/azienda/circular/case-study/Astelav_scheda_EN.pdf). These data were computed through a quantitative material analysis that took into consideration an average washing machine bill of materials, where the amount of resources needed for the replacement of the door seal and the circuit board was subtracted (since these two components are usually replaced during refurbishment). The figures are, thus, an estimate of the amount of resources saved by reconditioning and selling 1000 average second-hand washing machines onto the market, thus avoiding the need to purchase a new one.

3.1.2. Bundles

Bundles is a Dutch start-up born in 2014 that commercializes household appliances using servitized business models. The team employs 10 people and in 2016 reached 100 subscriptions. Bundles does not manage the production or transportation but takes care of the selling phase by offering pay-per-month and pay-per-use contracts. Customers do not pay the product but the laundry service it offers, transferring a fixed tranche or a quote based on water and energy consumption. The household appliances are Bundles propriety. Thus, at the end of the contract, Bundles recovers them, repairs parts (if necessary) and sells them back to another customer. In cases when the product cannot be repaired, Bundles sends it to the first supplier that can reuse the spare parts. Bundles collaborates with Miele, a household appliances Original Equipment Manufacturer (OEM), which guarantees the quality of products and helps create a circular supply chain. Moreover, Bundles supports the customers during the entire usage phase, offering maintenance services and personalized advice on how to use the device more efficiently. These services are possible thanks to digital technologies, such as IoT and Big Data. The devices are equipped with sensors that register information on the machine condition and on energy and water consumption. Data are sent to Bundles online platform and delivered to customers. Bundles contracts can be economically advantageous for clients, since the latter use a high-quality device without the need to buy it. Therefore, customers can save up to 1500 euros in the acquisition price of new household appliances, since instead of paying its full acquisition price at the time of purchase, they will pay the subscription fee during usage (1500 euro is the average acquisition price of a brand new washing machine, tumble dryer or dishwasher, according to company information). Bundles' activity also leads to environmental benefits, since the devices sold by Bundles are all A+++ ranked (lower energy, water and detergent consumption during usage) and pay-per-month and pay-per-use contracts facilitate reuse and recovering practices.

3.1.3. Bloomest

Bloomest is one of the most important brands in Europe for self-service laundries, based on appliances manufactured by Miele, the household appliances OEM. Since 2005, it helped more than 650 people open their own self-service laundry, mostly in the Italian territory. Bloomest activity simplifies the opening of new laundries, offering the possibility to share washing machines, thereby reducing the need for washing machines and tumble dryers to satisfy customers' request. The company also offers training courses and the chance to choose between different facilities from low budget ones to the most expensive but fully automated and built to reduce energy and water consumption. Moreover, Bloomest recently started a program to completely digitalize the self-service laundry. Digitalization allows connecting all the devices to a central system to monitor consumption and revenues. Small entrepreneurs that collaborate with Bloomest obtain economic benefits since designing and training costs are paid by the latter. The Bloomest initiative also has a positive impact on the environment since Miele produces high-quality and energy-efficient devices. Additionally, sharing models have the ability—in the long run—to reduce the number of devices placed on the market. If more people use self-service laundries, instead of buying a washing machine, the need of new products is reduced. In the long run, the stock of privately-owned washing machines decreases, while the idle capacity of laundries increases, since the same washing machine installed in a laundry room is used by several people.

3.1.4. Groupe SEB

Groupe SEB is a French multinational company with 20,600 employees and 6.8 billion € (2018) of annual turnover. It produces small household appliances and small electronic devices. It was founded in 1857. This large enterprise includes various B2C and B2B brands, as Moulinex, Rowenta, Lagostina, Silit and others. The group is worldwide extended. It distributes its products all around the world. Nevertheless, the 41% of sales is concentrated in the Western Europe. Recently, the company decides to guarantee a service life of at least 10 years for the new range of products. To attain this goal, Groupe SEB intervenes on the design side and offers maintenance and repair services. The new products are designed to be easily repaired, in a way to also simplify disassembly and re-assembly steps. Moreover, the repairability of the products is tested to consider potential improvements. To encourage customers in repairing their household appliances instead of replacing them, Groupe SEB provides an efficient technical assistance service. The repairing service is made by Groupe SEB professional technicians, while the nearest repairing center can be localized by web or by telephone support. To ensure the immediate availability of replacements, the company stocks the spare parts and guarantees the delivery at the reparation center in 48 h. Besides this traditional technical assistance service, Groupe SEB is testing 3D printing to produce spare parts in a way to reduce storage costs. 3D Printing spare parts allows reducing the need for moving them. Instead, only the digital file can be electronically sent directly to the technical assistance centers, in a way to manufacture directly on-site and on-demand only the parts needed for repair. Groupe SEB paid attention to circular design levers as design for easy maintenance and repair and for upgradability, to make possible the 3D printing of the spare parts directly in the technical service centers, and to design durability and life extension to ensure 10 years of lifespan. The company also adopted a product-oriented servitized business model, because providing the centers with the 3D printers puts the focus of the initiative on repair and maintenance operations. Regarding supply chain management, Groupe SEB has a partnership with Eco-Systémes in France for the collection of materials. Moreover, reverse logistics are established directly with the users, since they are rewarded with a coupon in exchange for their old products. Repairing products instead of replacing them reduces the environmental impact and can be economically profitable for customers.

3.2. Secondary Case Studies

3.2.1. Whirlpool (PolyCE Project)

Whirlpool is a household appliances producer, founded in 1911, that acts on a global level. Over 90,000 employs work for Whirlpool in about 70 production centers, for a total sale of about 21,000 million dollars. In 2017, Whirlpool joined the PolyCE initiative, a project financed by the UE Horizon 2020 program. About 20 companies and organizations are joining the PolyCE (Post-Consumer High-tech Recycled Polymers for a Circular Economy) initiative, committing themselves to develop correct practices in the production, use and disposal of plastic materials. Recycling plastics is still complex, and many security requirements, such as the conformity for alimentary contact or the durability of materials, are still uncertain, even for the more common materials such as Polyphenylene (PP) or Polypropylene Sulfide (PPS). To be effective from the production to the recycling phase, PolyCE brings together companies and organizations that act along the entire supply chain. Whirlpool, by joining this project, intervenes in the production phase by choosing recycled materials instead of virgin ones. Whirlpool manages to use up to 32% of recycled materials in the design of new appliances, according to the company's preliminary raw estimations (https://www.zerosprechi.eu/index.php/recupero-plastica-raee).

3.2.2. SOS Accessoire

SOS Accessoire operates is a French company founded in 2008 by Olivier de Montivault to help customers to repair their household appliances autonomously. The headquarter of the company is in La Verrière. The company employs around 25 people. SOS Accessoire offers a platform where customers can look for spare parts for their household appliances and order them on-line. SOS Accessoire sells the spare parts also on platforms such as e-bay or amazon. The company offers more than 25,000 spare parts that can be assembled using tutorial videos and instructions available through the online platform. The online platform contains 400 tutorial videos on how to replace parts and fix appliances. The use of the online platform is possible through a customer account. The platform helps customers to identify the problem, how to solve it and which is the replacement part to order. The order is usually processed in 3–4 days. SOS Accessoire collaborates with the main household appliances brands to guarantee the same characteristics and performances of the original products. Using the SOS Accessoire platform can be economically advantageous for customers. According to the company website, customers can save up to the 80% of the price that is normally charged by official technical assistance centers (https://www.sos-ricambi.it/chi-siamo.html). The SOS Accessoire initiative also has a beneficial impact on the environment perspective because it contributes to avoiding the disposal of broken household appliances that could be still exploited.

3.2.3. PocketWatt Project

PocketWatt is a three-year project that ended in March 2019, co-financed by the UE Horizon 2020 program. The objective of the project is to simplify the reading and comprehension of energy labels for European household appliances (washing machines, tumble dryers, dishwashers). Pocketwatt is also the name of the mobile App created to accomplish this purpose. The PocketWatt application is available on smartphones and laptops. It provides information on the environmental impact of household appliances, thus helping customers to compare products based on their energy efficiency. Customers can find information by scanning the QR code of products sold by those companies that participate in the project. This initiative helps to reduce energy consumption because customers are led to choose energy efficient products. The pilot project has been first developed in Spain and the UK, and has since been extended to the Czech Republic, Germany and Italy. The head team is independent and not related to any kind of company. To run in the proper way the project needs a strong collaboration between Original Equipment Manufacturers (OEM) and retailers. In fact, OEM must give to retailers the necessary details about the products, so that customers can consult them at the store. Using PocketWatt lead to save energy in the usage phase for customers and to reduce the environmental impact. OEM and retailers participating in this project improve their green brand image as companies that take into consideration the environmental aspect.

3.2.4. AquaFresco

AquaFresco is a mechanism designed by three MIT graduate students to reuse washing machines' wastewater. The AquaFresco project won the third prize of the "Water Innovation Prize Competition" in 2014. The AquaFresco system enables the reduction of water consumption, cleaning up the water after its first use and reusing it multiple times. The mechanism uses a polymeric filter that cleans up the water, recovering 95% of the washing cycle's water. According to the three MIT designers, thanks to the implementation of this mechanism, users could reuse the same water. The device consists of a stand-alone unit that can be paired with different kinds of washing machines. The idea of the designers is to create a device that can be paired with three or five washing machines at the same time. Up to now there are three hotels and three laundry-services that are testing the system in the US. Moreover, the system can be ameliorated using IoT to control the water quality. This system allows to obtain environmental and economic benefits. The AquaFresco system, indeed, reduces the overuse of water and water pollution. The large-scale use of this technology can also be economically advantageous. According to some estimates made during the project, a big hotel that spends about 10,000 dollars per week in water and detergents could save 500,000 dollars per year using the AquaFresco system.

3.2.5. Gorenje

Gorenje is a household appliances OEM, founded more than 60 years ago. The headquarter is in Velnje (Slovenia) but Gorenje operates in 90 countries. The company employs about 11,000 people and has a turnover of 1.3 billion euros. Gorenje products can be bought on the company online platform but are generally sold by retailers. In 2014 Gorenje joined ResCoM (Resource Conservative Manufacturing), a project co-financed by the EU under the Horizon program, which saw the participation of 12 organizations. The project ended in 2017 and aimed to promote CE initiatives, helping companies in the transition from linear to circular practices. Gorenje, thanks to ResCoM, developed a new business model for washing machines based on leasing contracts. In this new approach, washing machines are firstly sold to premium clients, which use them for a pre-defined period; then, the devices are recovered and re-sold to customers with a lower budget. Gorenje simplifies remanufacturing activities directly in the design phase by conceiving washing machines with a modular structure and standard components. Gorenje is also considering adding sensors to the washing machines to obtain information on the devices conditions as well as energy and water consumption. The project has been followed by ReCiPSS (Resource-Efficient Circular Product-Service-Systems), again co-financed by the EU. Gorenje, thanks to the new investments provided by ReCiPSS, will test the new business model on a large-scale. Gorenje estimated that this new approach could lead savings for each washing machine of about 146 kg of virgin materials, 21 kWh of energy during the production phase and 18 kWh of energy during the usage phase, for a total of 25,000 tons of Carbon dioxide equivalent.

3.2.6. Homie

Homie is an initiative developed in Delft university (Delft university of technology, the Netherlands) to test new business models in the white goods market. Homie focused on the move from classic buying and selling contracts to pay-per-month and pay-per-use contracts. Homie provides services in the cities of Rotterdam, Delft and the Hague. Homie intervenes in the selling and usage phase, managing the contracts and supporting customers who wish to access washing machines and other household appliances instead of buying them. Homie offers washing machines produced by Zanussi-Electrolux to guarantee high quality and A+++ ranked devices. During the usage phase, Homie provides repair services and advice on how to use the device more efficiently. At the end of the contract, Homie sells the washing machines to other customers, repairing them if necessary. Customers pay monthly and the rate differs based on the number and type of washing. Sensors placed in the washing machines allow Homie to track how customers use the devices. Homie uses data and information collected by sensors not just to calculate the monthly rate but also to implement a personalized customer experienced, advising on how to use the device in the best way possible. The initiative found its primary source of enhancement in the Technology Foundation branch of the NWO (Netherlands organization for scientific research), an organization under the control of the Ministry of Education. Then, in 2018, Homie received funds by the EU program ReCiPSS. Homie activity is beneficial for customers and the environment. Customers can use high-quality washing machine paying less, thanks to pay-per-month contracts. In turn, pay-per-month contracts make it easier to close the loop and reuse products. Together with the more efficient use of washing machines, Homie reduces waste and brings benefits for the environment.

3.2.7. The Machine du Voisin

The Machine du Voisin is a French initiative developed by four students of the Skema Business School. The objective of the project is to connect washing machines owners who want to share their device with people lacking the possibility of owning one. The students created a platform where washing machine owners can register their device, specify the place and time that it is available and make arrangements with the other members of the platform that need to use the washing machine. This initiative focuses on sharing, changing the classic business model, thus reducing the total number of washing machines on the market. Customers that want to access the service need only to register on the platform. Moreover, on the platform, they can leave comments and read other customers' experiences. This initiative can be economically beneficial for clients, since machine owners can ask for a modest remuneration. Moreover, people with low budget or space problems do not need to own a washing machine but can use a washing machine available on the Machine du Voisin.

3.2.8. L'Increvable

L'Increvable is the name of Julien Phedyeff's project of a washing machine built to last 50 years. Julien Phedyeff is a designer graduated at the École Nationale Supérieure de Création Industrielle of Paris. He presented the project in 2015 at the Observeur du design, a contest organized by the APCI (Agence pour la Promotion de la Création Industrielle) recognized by the French Economy ministry, Finance ministry and Culture ministry. L'Increvable is a washing machine designed to extend its life cycle, thus opposing planned obsolescence. To achieve this goal, Phedyeff designed a washing machine extremely easy to assemble and disassemble, to simplify repairing and substitution practices.

Thanks to this design, the washing machine would not be easily discarded. The customer can repair the device on their own, saving on repairing and maintenance costs. To help customers in the repair activities, Phedyeff created an app that provides tutorials on how to assemble and repair the washing machine. Moreover, the washing machine is also designed to change aesthetically by modifying the color; in this way, the possibility of emotional obsolescence is considered. To offer a high-quality product at an affordable price, the washing machine is created to be assembled by customers, to remove assembly costs from the final price. Since the Phedyeff's washing machine is built to last, it is a possible solution to reduce resource exploitation and excessive waste production. Unfortunately, the project was suspended in February 2020 because of a lack of industrial and financial partners to finalize its development and allow its commercialization.

3.2.9. WeWash

WeWash is a spin-off project born in the context of the multinational company Bosch. Bosch is a historic German brand founded in 1886 that produces spare parts for the automotive and household appliances. WeWash is the initiative of three Bosch members that created an app to simplify the sharing of washing machines. In 2014 they proposed the idea to Bosch and a year later they set up their own company. They collaborated with the Bosch Thermotechnology team and Bosch supported the initiative, presenting it at organized events. The objective of WeWash is to promote sharing to reduce the number of washing machines on the market. Customers who want to use the app should register on a dedicated platform. The platform allows to verify if somebody is using a shared washing machine, reserve it and track when the wash cycle is finished. This initiative modifies the usage phase thanks to digital technologies. To use WeWash, an IoT kit is sufficient and adaptable to every kind of washing machine. The IoT kit is placed between the device and the power plug. Moreover, WeWash accepts credit card, simplifying payments. The "Citadines Arnulfpark" hotel and "The Reserl" student residence, both in Monaco, are testing the WeWash service. At the hotel, clients can choose to use their account or the centralized account of the hotel. The hotel can, indeed, offer an extra service for clients and, at the same time, save money on manual billing and coin acceptors.

3.2.10. Electrolux (Zero Landfill)

Electrolux is a household appliance manufacturer based in Stockholm that has been in business since 1919 and sells more than 60 million products worldwide per year. In 2017 Electrolux launched the 'Zero landfill' program, to promote waste reduction and recycling practices inside its factories. The project was launched at the beginning in five factories: Adelaide (Australia), Kinston (USA), São Carlos (Brazil), Siewierz (Poland) and Solaro (Italy). Since January 2018 it has been extended to all plants of the Electrolux group. For this initiative, Electrolux has identified a set of steps to follow to be able to contain the disposal of waste in landfills: monitor waste data inside the factory, define a plan towards the 'Zero Landfill,' give priority to waste reduction strategy, involve all the workforce by promoting a culture of sustainability, develop stronger partnership with suppliers, mobilize to resolve normative and legislative challenges, invest in continuous improvement and finally share best practices with the other factories. More specifically, at the Solaro plant in Italy, the company undertook a waste monitoring activity to improve its management and to identify the reduction priority areas. A first change was made by reorganizing the ecological platforms of the production sites and by improving the waste separation process: a new codification system and new bins have been introduced. In addition, Electrolux has started to use compactors to optimize waste transport, thus reducing the volume of waste generated and increasing the number of units that can be transported on each route. The company does not personally take care of the recycling process. However, since 2018 it requires its partners to provide a declaration that verifies the quantities and destination of the waste disposed of. Thanks to 'Zero landfill'—and according to company declarations—Electrolux recovered more than 2400 tons of waste. This initiative has led also to economic benefits for Electrolux, in terms of savings in waste management costs; the Solaro plant in Italy reported, in 2017, a reduction of 15,000 euros.

3.2.11. Miele

Miele is a German company that produces household appliances. It was founded in 1899 in Herzebrock by Carl Miele and Reinhard Zinkann. In 2018 the company had 4.16 billion € of annual turnover and more than 20,000 employees worldwide. Miele has locations in 50 countries, with its own sales subsidiaries and 12 production sites. The company approached CE with the aim to increase the energy efficiency of appliances and to use recycled plastics in the production of new products. Miele aims to produce long lasting washing machines with recycled materials and as few different typologies of materials as possible. In the design stage, Miele takes care to use plastics of the same type, wherever possible, in order make the products recyclable or to make recycling easier. Composite materials, i.e., non-separable materials that cannot be recycled together, are avoided where possible. The two R strategies pursued are reduce and recycle, since the company has the objective to increase the quantity of recycled plastics inside the production of new appliances. For instance, Miele washing machines are recognized as appliances that last for long time and are made with recycled materials. The product may cost more than others, but it is a synonymous of high quality and long durability. Several circular product design practices are adopted: design for durability and life extension, because Miele washing machines are designed to have a functional life of 20 years; design for upgradability, since service engineers can provide software upgrades for the machines; and material selection by producing the washing machines with a percentage of recycled materials. Overall, environmental benefits are achieved. According to company declaration, new washing machines use around 20% less water and 30% less energy than their predecessors.

3.2.12. Relight

Relight is a company founded in Milan in 1999 that manages waste collected in the Italian territory. The company focuses on WEEE and more specifically on appliances, fluorescent lamps and cathode-ray-tube devices. Relight owns a specific disposal center and has the Italian authorization to process and recover waste. Relight has an internal vehicle fleet and directly control waste transport. Moreover, the company is also part of the Italian 'Albo Gestori Rifiuti,' so it can transport hazardous waste. Relight treats waste whenever possible or connects its clients with external disposal companies. Relight treats glass, metal and rare earth elements. From its birth, Relight has recovered 2500 tons of glass from old TVs, reusing it to produce ceramic tiles. Relight puts waste back into the production chain, thus helping to reduce the resource consumption and the related environmental impact.

3.2.13. The Restart Project

The Restart Project is a people-powered electronic start-up, born in 2013 and based in London, UK. The company has nine workers supported by other volunteers and a total gross income of about 245,000 £ (2017). This project does not only act in the UK, but it is globally extended, having over 60 groups in 12 countries: Argentina, Australia, Belgium, Benin, Canada, Colombia, Germany, Hong Kong, Iceland, Ireland, Italy, Norway, Spain, Sweden, Switzerland, Tunisia, UK, USA and Uruguay. Furthermore, this initiative is supported by the UK's government and other organizations. The objective of this CE initiative is teaching people how to repair damaged appliances and electronic components through free access events named 'Restart Party.' In fact, the actor of this business case is the Restart Community, which organizes the parties to encourage and empower people to use their electronics and household appliances for longer, by learning repair and maintenance. Overall, the lifespan of the devices is prolonged thanks to the repair and upgrade interventions made at restart parties. In other words, the company focus on the reduce strategy, because repairing broken devices implies an increase of the product lifespan, which leads to a decrease in the number of products in circulation. This approach to the devices failures also allows the collection of a huge amount of data on recurrent faults and other barriers to repair, to provide a strong quantitative analysis on the positive benefits that can be brought about by repair and reuse. The company also promotes the use of 3D printing technology at the Restart parties, to print instantly the components necessary for every fault case, making possible a quick reparation of the devices. Users have an active role in this initiative during the usage phase, since they learn how to repair their devices by themselves, instead of discarding them when something is not working properly. The business model is servitized and product-oriented, since it is focused on repair services where all the activities are aimed at prolonging the lifespan of electronic devices. Furthermore, the Restart Project is part of a wider ecosystem, thanks to collaborations with schools that teach how to repair the various faults to the restarter community. Thanks to this initiative, users can save money through repair by using the same device for a longer time: in fact, the slogan of this project is 'Don't despair, just repair.' The environment encounters benefit too, in terms of a reduction of waste.

3.2.14. Coolrec

Coolrec is a European recycling company based in Waalwijk, the Netherlands. The company has eight sites across Belgium, the Netherlands, France and Germany and can offer logistics and processing in 24 EU countries. Coolrec has 20.43 million $ (2016) of annual turnover and 58 employees distributed in all the production sites. The objective of this CE initiative is to separate plastics from discarded appliances that are processed so that they can be reground and used to produce new recycled plastics and metals. Coolrec takes on plastics from household appliances and electronic devices from Uruguay, Martinique, La Reunion and Sri Lanka and treats them in its production plants in Europe to produce new raw materials, such as recycled plastics and metals. This recycling process starts from the collection of fridges, washing machines and other electronics; then, there is the sorting of the various typologies of materials; finally, the process of regrinding gives new plastics and metals as outputs. The new materials coming out from the process are used to produce new goods. Supply Chain management is relevant for this case study, especially regarding collaboration and reverse logistic. In fact, Coolrec has a partnership with Philips and Veolia for the collection, the treatment and the production of vacuum cleaners; moreover, the company also works with Miele and a coffee machine producer, making possible the production of machines with the recycled raw materials coming from the waste from the company itself. Regarding the reverse logistic, Coolrec directly collects the discarded products in Uruguay, Martinique, La Reunion and Sri Lanka and brings them into its production plants for the reprocessing. Coolrec activity contributes to achieving environmental benefits, since waste is reduced and secondary raw materials are produced thanks to recycling.

3.2.15. Norsk Ombruk

Norsk Ombruk is a Norwegian company founded in 2013. It has an annual turnover of 1.6 million € (2016), and it employs approximately 25 employees. The aim of the company is to give a new life to household electrical goods (such as fridges, freezes, stoves and washing machines), through the collection of old devices, their repair and remanufacture interventions. The company collects used household appliances at the end of their first lifecycle (usually after five years) and, if they pass a quality control, remanufacture them to tip-top conditions. Remanufactured products are sold again and covered with six months of warranty. Users have an active role in this process, since they must decide to give a second life to a reconditioned appliance, instead of buying a new one. Partnerships with other companies at a supply chain level is a very important aspect of this business. In fact, Norsk Ombruk has collaborated with Electrolux since 2016, to recover and sell Electrolux products that cannot be sold via other channels for various reasons (e.g., early damage). The company also collaborates with retailers, such as Ikea or Elkjop, to improve the reselling of remanufactured household appliances. The Norsk Ombruk remanufacturing business model provides several benefits. Remanufactured products are a good alternative to new ones, since they cost less. In this case, lower income families can then afford higher quality, energy-efficient products. On the other hand, the supply chain achieves cost savings since it avoids landfill and disposal costs on old products. Lastly, this CE case adds benefits to the environment since it prevents waste and allows to save resources.

3.2.16. Repair Café

Repair Cafés are meeting places where people find support (such as free tools and materials and expert volunteers) to help themselves in repairing things such as electronics and small household appliances. They are managed by the Repair Café Foundation, a non-profit organization who wants to make repair a completely normal activity in local communities. The first Repair Café was organized by Martine Postma in Amsterdam, on October 2009. To date, there have been over 1500 Repair Cafés worldwide. People who have broken products can bring them to a Repair Café, where they collaborate with specialists in an ongoing repair learning process. People who usually access Repair Cafés are not customers of professional repair specialists, since they normally discard broken items. Consequently, there is no competition between Repair Cafés and professional repair specialist. Repairing a broken household appliance avoids its substitution, which thus avoids having to bear the price of a new product. Repair extends the life of products that would otherwise be discarded. This reduces the volumes of materials and energy needed to manufacture new products, also cutting CO_2 emissions. Repair Cafés are also a good strategy to involve people with practical skills who have previously lost their jobs, and might otherwise be sidelined.

4. Analysis and Discussion

The classification of the 20 cases through the Research Framework provides an overview of the implementation of CE in the household appliances industry. Results are reported in Table 1.

Table 1. Overview and classification of cases.

	Circular Economy 4R Strategies				Circular Economy Levers			Enabling Role of Digital Technologies				Circular Benefits			
Case	**Reduce**	**Reuse**	**Remanufacture**	**Recycle**	**Circular Product Design**	**Servitized Business Model**	**Supply Chain Management**	**Internet of Things**	**Big Data & Analytics**	**Cloud Platform**	**3D Printing**	**Environmental Benefits**	**Economic Benefits (User)**	**Economic Benefits (Supply Chain)**	**Social Benefits**
Astelav (Ri-Generation)			X			X	X					X	X	X	X
Bundles	X	X				X	X	X	X	X		X	X		
Bloomest	X					X	X	X				X		X	
Groupe SEB	X				X	X	X				X	X	X		
Whirlpool (PolyCE)				X	X		X					X		X	
SOS Accessoire	X					X				X		X	X		
PocketWatt	X						X			X		X	X	X	
AquaFresco	X				X			X				X		X	
Gorenje	X	X	X		X	X	X	X	X			X			
Homie	X	X				X	X	X	X			X	X		
The Machine du Voisin	X					X				X		X	X		
L'Increvable	X				X	X						X	X		
WeWash	X					X		X		X		X	X	X	
Electrolux (Zero Landfill)	X											X		X	
Miele	X			X	X							X			
Relight				X			X					X			
The Restart Project	X					X	X				X	X	X		
Coolrec				X			X					X			
Norsk Ombruk			X				X					X	X	X	X
Repair Café	X					X						X	X		X
Total	**15**	**3**	**3**	**4**	**6**	**12**	**12**	**6**	**3**	**5**	**2**	**20**	**12**	**8**	**3**

"X" means that the i-th case considers the j-th element.

4.1. Circular Economy '4R' Strategies

The literature proposes an ideal hierarchy to follow among the 4R strategies to achieve CE [10]. This hierarchy considers reduce practices as the most valuable, followed by reuse, remanufacture and recycle, since much of the value remains in the product [43]. Accordingly, organizations should at first implement resource efficiency and waste prevention. Then, they should try to reuse products as much as possible. When reusing is not feasible, they should try to remanufacture them. Lastly, they should recycle waste to recover raw materials. The initiatives in the paper slightly follow this hierarchy, since 15 cases on a total of 20 follow the reduce strategy, while 3 exploit reuse practices, 3 initiatives concern remanufacture and 4 initiatives pursue recycling (Figure 2). Even though some literature claims that reduce strategies do not deal with waste [6], they are worthwhile for a CE. Reduce is a prevention approach, and it is the first step to reach a CE because it deals with the potential abolition of the concept of waste. On the contrary, strategies such as reuse, remanufacture and recycle deal with the reprocessing of products which are already or nearly waste. Nevertheless, the initiatives investigated show that recycling practices are more common in the household appliance industry than reuse and remanufacture. This can be explained by the fact that household appliances have long been subject to the WEEE legislation. For instance, in Europe, the 2002 WEEE Directive, and its recast in 2012, sets targets for the collection and recycling of the waste from household appliances [44]. According to the literature, CE initiatives should apply the 4R strategies in a systemic cascading process [9,45]. However, no initiative pursues all the 4R concurrently, and most of them (16 out of 20) employ only one single strategy.

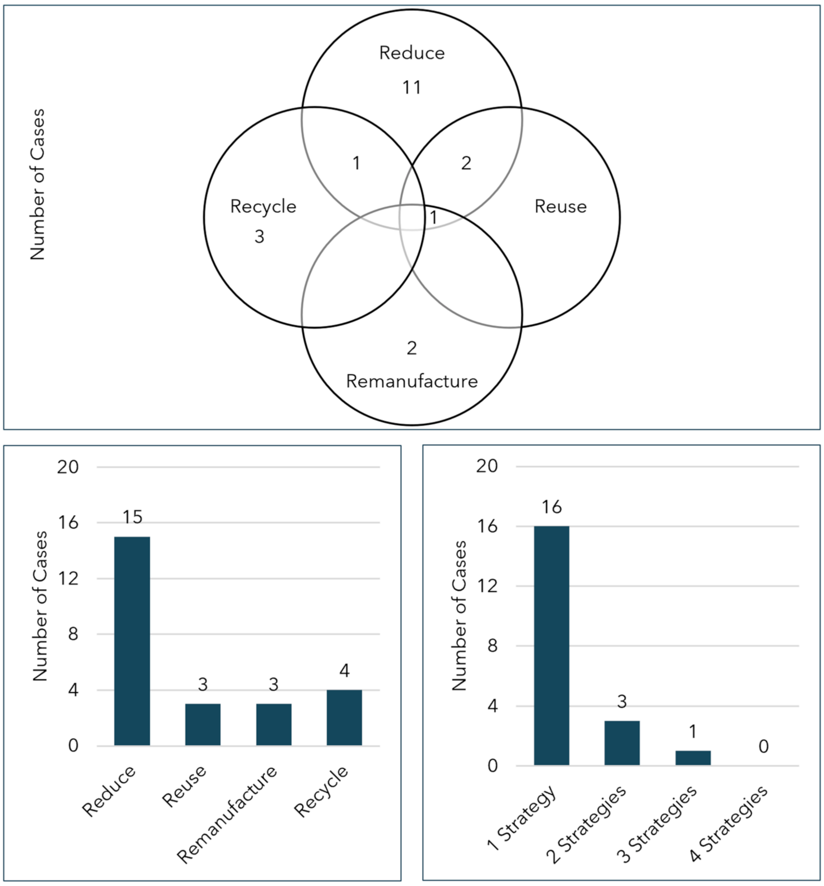

Figure 2. Circular Economy '4R' strategies in the household appliance industry.

4.2. Circular Economy Levers

The levers mostly employed are, from one side, the shift from linear sales to servitized business models and, from the other, supply chain management (Figure 3). In fact, 12 cases out of 20 apply servitized business models to facilitate the transition towards CE. These could be easier to implement than circular design strategies since changes in the business model do not require to modify facilities or production techniques. On the other hand, supply chain management has been adopted especially through collaboration and reverse logistics. The high number of initiatives that applied collaboration confirms the need for a more holistic and shared approach for the transition to CE. Circular redesign is still a practice rarely used, since only 6 cases out of 20 introduced circular design practices in their production processes. Approaches to easier disassemble or improve material selection are still in a prototypical phase and are far from being implemented on an industrial scale. There are, indeed, many circular design ideas and proposals, but they need a radical change as well as extensive funding. The analysis also shows that 7 cases out of 20 combine two levers to achieve CE. However, only two initiatives employ them all. In its pilot project, Groupe SEB leveraged 3D Printing to enable repair services (product-oriented servitized business models) on products purposely redesigned for enhancing repair and parts substitution (circular design) in strong collaboration with technical assistance centers (supply chain management). By joining the ResCoM and the ReCiPSS EU-funded projects, Gorenje leveraged IoT to offer washing machines through leasing-based as-a-service contracts (servitized busines models), these washing machines are redesigned for enhancing remanufacturing (circular design), in joint collaboration with an ecosystem of actors such as technology providers (supply chain management). Despite these two exemplary cases, systemic initiatives of a joint adoption of CE are lacking. It is worthwhile to stress that both the initiatives are far from achieving an industrial scale, since to date both Groupe SEB and Gorenje are still running pilot projects.

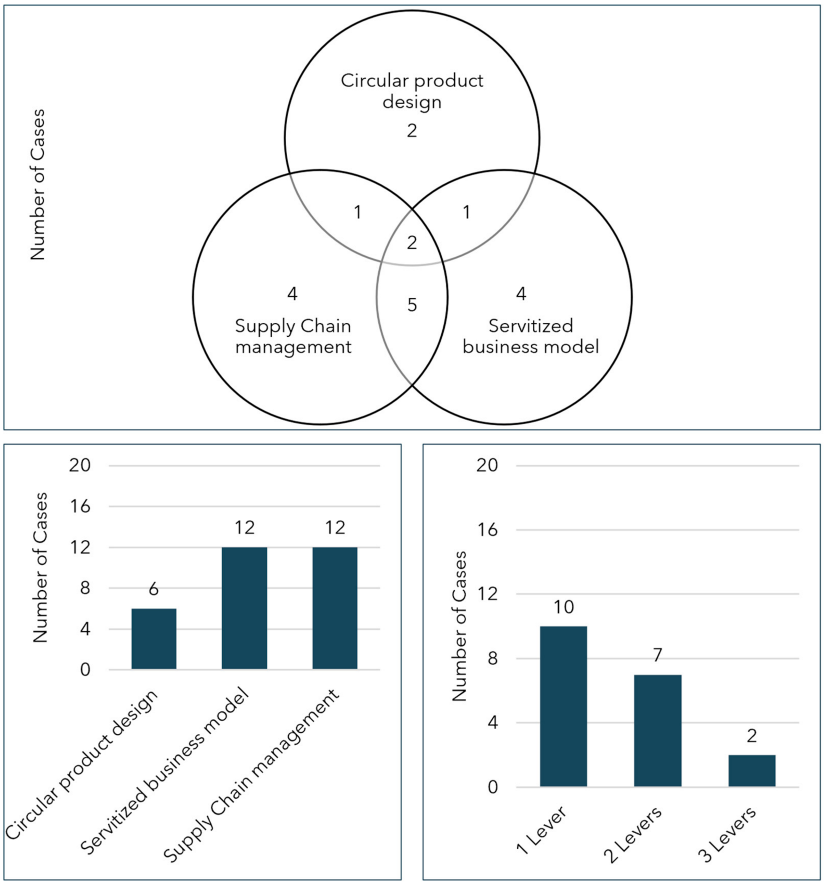

Figure 3. Circular Economy levers in the household appliance industry.

4.3. The Enabling Role of Digital 4.0 Technologies

The IoT is a technology used by several initiatives that makes possible the data collection indispensable to offer servitized business models such as pay-per-use contracts. Big Data and Analytics generally employ data collected through IoT to create customer value in the service offering. They imply a more accurate analysis and have thus been exploited by fewer initiatives. Cloud platforms are required especially for initiatives based on sharing. Platforms, indeed, revolutionized the organization of sharing, allowing to extend it to the entire digital community. These three technologies emerged as relevant for the servitization of business models, where appliances are offered as-a-service: IoT is used for collecting data from users and for billing purposed, Big Data are analyzed to personalize the service offer in order to respond to customer needs and Cloud platforms are used to enhance appliances sharing (Figure 4). On the other hand, 3D printing emerged as relevant for repair processes, even though still quite underdeveloped (only 2 cases out of 20 adopted such a technology). Overall, the number of initiatives that employ at least one digital technology is remarkable (7 out of 18), but there is still room for extension and for a joint adoption of all these technologies. In this regard, the initiatives that apply 3D printing are part of a different context, so that it is not unexpected if 3D printing appears alone, not combined with the other technologies. However, a simultaneous use of IoT, Big Data and Cloud would be desirable, since they deal with the same set of data. The exploitation of digital technologies can be extremely advantageous, but many organizations may consider this investment too risky.

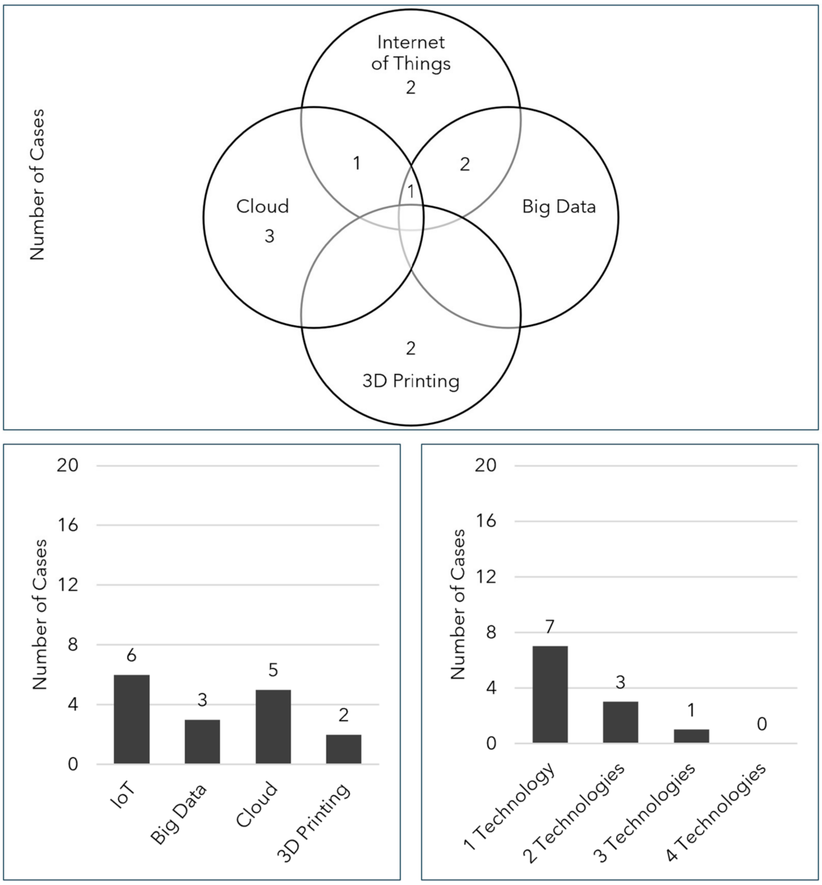

Figure 4. The Circular Economy enabling role of Digital 4.0 Technologies in the household appliance industry.

4.4. Circular Benefits

From the analysis of the 20 cases emerges that each initiative reached environmental benefits (Figure 5). This is an expected result, matching the origins of CE. Benefits for customers immediately follow: 12 cases out of 20 obtained these goals. Benefits for customers are indispensable to achieve a change in customer behavior and to allow the initiatives to consolidate and scale-up over time. Eight projects out of 20 increase profit for the supply chain, by paying less in materials, and by saving on dismantling and landfill costs (e.g., Norsk Ombruk). Interestingly, no case mentioned potential benefits regarding the compliance to environmental regulation such as carbon taxes. This can be explained by the fact that information coming from companies' websites may focus on drawing attention to benefits for customers or for the environment, rather than on positive consequences for the supply chain. Nevertheless, great attention should be paid to them. Otherwise, companies and organizations would not be prompted to take the potential risks related to a significant change in their way of doing business. Finally, only three cases reached social benefits. Even though academics stress that a CE model should include the social sphere [46], very few companies in the household appliance industry focus on them. Globally, only 3 initiatives out of 20 achieved all the four categories of benefits. It is important to stress that it is now necessary to consider CE in a more holistic way, to include the three pillars of sustainability.

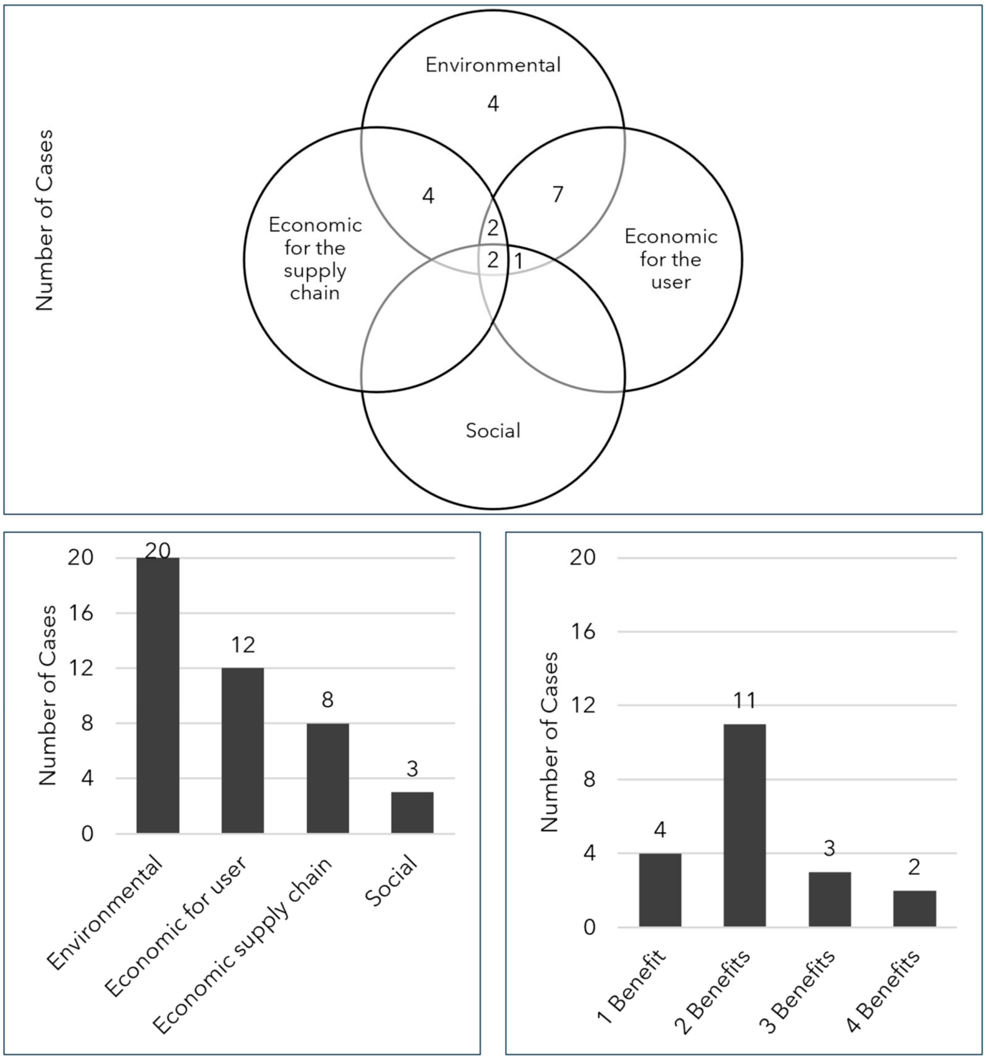

Figure 5. Circular Benefits in the household appliance industry.

4.5. *Patterns of Adoption of Circular Economy in the Household Appliance Industry*

Based on the cases analysis and on the above discussion, two main different patterns of adoption of CE in the household appliance industry emerged from the cases, i.e., incremental vs. radical adoption approaches, as shown in Figure 6. Figure 6 highlights only the CE Research Framework elements (i.e., strategies, levers, enablers and benefits) touched by incremental and radical adoption patterns, respectively. While incremental approaches seek to improve existing products and systems in little steps, radical ones focus on new, disruptive innovations in markets, technologies or business models [23,47].

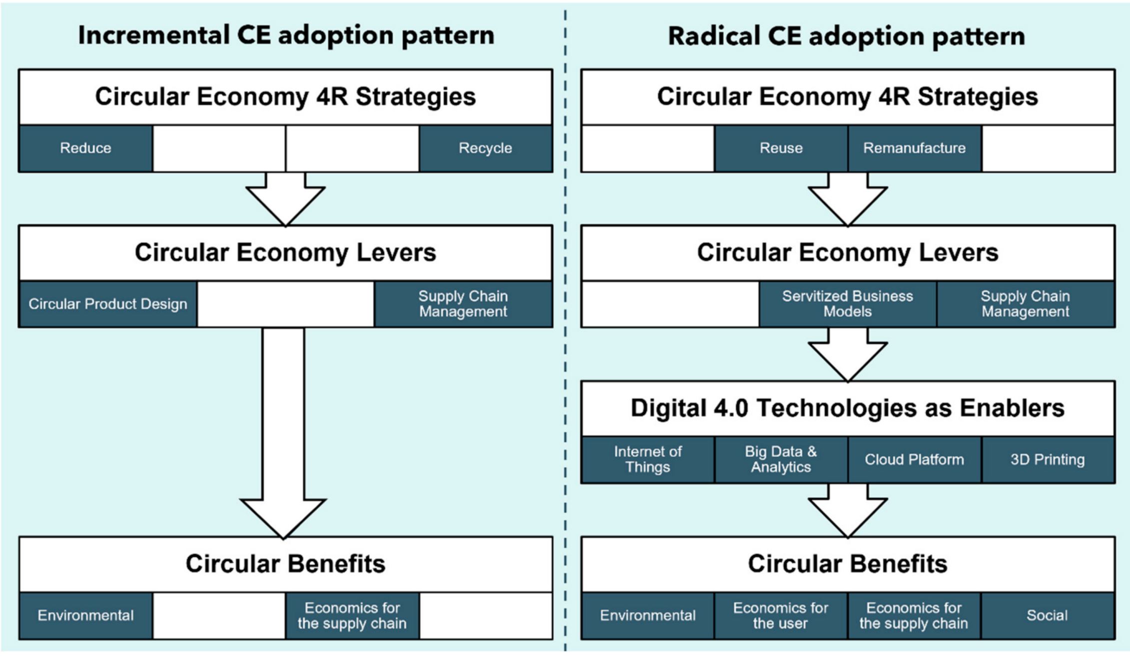

Figure 6. Incremental vs. Radical Circular Economy adoption patterns.

The incremental CE adoption pattern in the household appliance industry is led mainly by original equipment manufacturers, which favor practices focused on reduce and recycle strategies. For instance, Whirlpool (with the PolyCE project) managed to increase the usage of recycled materials in the design of new appliances. Miele approached CE with the aim to increase the energy efficiency, the lifespan and the recycled contents of appliances by design. Electrolux, with the Zero Landfill project, promoted waste reduction and recycling practices inside its factories. Reduce and Recycle strategies are pursued by the companies thanks to an incremental redesign of appliances for the CE, with the aim to increase appliances life, improve their energy efficiency and augment the share of recycled contents, especially plastics.

The radical CE adoption pattern in the household appliance industry is, on the other hand, led mainly by startup or 'outsider' companies, as in the case of Homie, L'Increvable or Bundles. Even when original equipment manufacturers are involved, they are not the focal actor who oversees the initiative, as in the case of WeWash (Bosch). These radical CE adoption patterns are focused on disruptive CE practices based on reusing, remanufacturing and sharing. Digital 4.0 technologies are a strong enabler of these kinds of patterns. As exemplified in Section 4.3, investing in IoT, Big Data and Cloud enables servitized business models focused on reuse and remanufacture, and sometimes on sharing. This radical change is, however, rarely directly taken by manufacturers. This can be explained by the fact that a radical adoption pattern of CE requires several cycles of business model experimentation (see e.g., [47]), with uncertainties on results and risks of unsuccess. Nevertheless, public funding can help in overcoming this obstacle, as exemplified by the Gorenje case, an appliance manufacturer who experimented leasing models on washing machines under several EU-funded projects. Lastly, radical CE adoption patterns emphasize more the achievement of social and economic benefits to users, as exemplified by the Restart Project or Repair Cafés.

5. Conclusions

This exploratory research lays the foundation for a stronger and more systemic understanding of the adoption of CE in the household appliance industry. The analysis contributes to research by providing a systematization and several observations on how CE is adopted by the household appliance industry. First, we have seen that the 4R hierarchy is slightly followed, since 15 cases pursue reduce strategies, 3 exploit reuse practices, 3 concern remanufacture and 4 deal with recycling. However, cascading is still poorly addressed in the household appliance industry, since 16 out of 20 cases employ only one strategy, and no initiative pursues all the 4R concurrently. Second, while we have ascertained that servitized business models (such as leasing or pay-per-use) and supply chain management practices turned out to be the most used levers, little attention is still devoted to circular product design practices. Third, the analysis of the cases allowed us to recognize that digital 4.0 technologies as IoT, Big Data and Cloud are usually employed to start a servitization journey towards CE. On the other hand, the industry is starting to use 3D printing as an enabler of repair practices. Fourth, we have seen that few cases lead to the achievement of social benefits, even though academics stress their relevance for CE. This study also recognizes two main different patterns of adoption of CE in the household appliance industry: incremental and radical CE adoption approaches. We found that incremental CE adoption patterns are based on design practices focused on reduce and recycle strategies. Incremental patterns are mainly led by original equipment manufacturers. On the other hand, radical CE adoption patterns are focused on disruptive practices based on reuse, remanufacture and sharing, where Digital 4.0 technologies have a strong enabling role. Usually, these patterns are led by startup or 'outsider' companies.

From a practical point of view, this study supports an improved managerial understanding of the adoption of CE in the household appliance industry. This research deals with decisions at the strategic level, where a high-level approach in decision making is expected. A decision-maker in the industry can infer from our study what actions are most typically adopted by companies in the sector, and what benefits are achieved. This can support benchmarking activities as well as the planning of CE projects.

Lastly, this study presents limitations. The analysis is still at a high-level and quite descriptive, mainly due to the limited number of primary cases, the difficulty of verifying secondary cases results, and the limited amount of initiatives examined. An extension of the database could lead to increase results robustness, especially by conducting more primary case studies. Additionally, this study considers only the household appliances industry. Given the high generalization potential of the Framework, an application to other industries (as the electronics, ICT or automotive) is suggested. Researchers should start from these gaps and expand the number of case studies and the applications to other sectors. Lastly, future research is necessary to follow up this exploratory study by comparing the results regarding the 'how' and 'what' questions (i.e., the strategy, levers and enablers emerged) in a real environment through Action Research, and the results regarding the 'why' question (i.e., the benefits) through quantitative methodologies for the assessment of economic, environmental and social impacts (such as Life-Cycle Assessment and Life-Cycle Costing).

Author Contributions: Conceptualization, G.B. and N.S.; Data curation, G.B. and I.B.; Formal analysis, G.B.; Investigation, G.B. and I.B.; Methodology, G.B., N.S. and I.B.; Project administration, M.P.; Supervision, N.S. and M.P.; Validation, N.S. and M.P.; Visualization, G.B. and N.S.; Writing—original draft, G.B. and I.B.; Writing—review and editing, G.B. and N.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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