A new framework for assessing circular economy scenarios in the washing machine industry

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Abstract: Although the circular economy is usually indicated as a way to reconcile economic growth and sustainability, circular economy business projects are not implemented on a large scale yet. Developing new methods able to demonstrate the economic, environmental and social benefits of circular economy scenarios can support stakeholders to embrace this transition. This paper proposes and discusses the actions required for reshaping the washing machine industry towards a more circular economy scenario. Thus, an overview of a new framework, based on the results of a literature review, is provided. Albeit the research is only at its initial stage, the new framework described in this paper can be used to support static simulation and what-if analysis. With the aim to provide an idea about the order of magnitude of benefits gathered by a circular economy transition, the outcomes of some preliminary computations are estimated and discussed. Results show that customers could benefit from an average yearly saving of almost 30% of the current washing cost, while the country energy generation and water consumption could be reduced of about 0.6% and 1% respectively. Although they are only preliminary, these results show how such a model can contribute to reduce the uncertainty that typically characterize circular economy transition.

Keywords: circular economy, washing machine industry, sustainability framework, circular business model.

1. Introduction

Circular economy has reached increasing attention in recent years, from both companies and policymakers. For instance, China has issued a circular economy law in 2008 with a top-down approach, based on the "command and control" principle rather than market instruments, as in the European, American or Japanese policies (Ghisellini et al., 2016). In general, circular economy is indicated as a way to reconcile economic growth and sustainability (Ellen MacArthur Foundation, 2012). Several studies have shown clear environmental and social benefits related to circular economy scenarios in different industries. For instance, shifting from a linear to a circular supply chain in the cases of insulation materials, biodiesel and chemicals allows to achieve significant reduction in CO2 emissions (Nasir et al., 2017; Genovese et al., 2017). Moreover, implementing a reuse policy for white goods can bring advantages to the society as a whole, since it increases job opportunities and it provides low-price refurbished appliances to low income households (O'Connell et al., 2013). However, circular economy solutions could be challenging from an economic point of view (Genovese et al., 2017). Thus, real circular economy projects are not always taking off so far, especially due to barriers like risk of cannibalization, fashion vulnerability, financial and operational risk, customer irrationality, lack of supporting regulation and little knowledge about circular economy and its principles (Kissling et al., 2013; Linder & Williander, 2017). In order to foster the circular transition, the overall purpose of this paper is to propose and discuss a systemic framework for assessing circular economy scenarios in the washing machine industry. The research presented in this paper is still at a preliminary stage and it will be further deepened by a three-year study. However, the aim of this paper is to highlight and to provide insights regarding: (i.) the problem context and the background; (ii.) the actions needed to trigger this transition; (iii.) an overview of the framework and (iii.) a preliminary computation of the expected impacts. To this purpose, section 2 provides a literature review on circular economy and washing machines, based on a preliminary research conducted on Scopus and improved with cross-references analyses. Section 3 describes the set of envisaged actions, while the framework is proposed in Section 4 and a short discussion of the expected impacts is detailed in Section 5. Finally, concluding remarks and a future research agenda are reported in Section 6.

2. Literature review

2.1 Circular economy

The dominant neoclassical economic model, based on growth and throughput, reflects linear material flows (Ness, 2008) in which resources are taken from natural finite stocks, products are manufactured from these resources, sold to consumers and then disposed as waste after use. The principle underlying this linear flow is a cradle-to-grave concept through industrial systems (Braungart et al., 2007), where these cycles of production and consumption inevitably transform resources into waste. Moreover, the economic growth is directly connected to material and energy flows, in what might be called the "river economy" (Stahel, 1997). The classical linear economy paves the way for the so-called "throwaway society", based on manufacturing of short-lived products, planned obsolescence, economies of scale and a consequent ever growing demand for new products by consumers (Mont, 2008). This linear model relies on large quantities of cheap and easily accessible materials and energy: during the last century the total material extraction has exponentially increased by a factor of 8 and there is no evidence that this growth will slow down or eventually decline (Krausmann et al., 2009). Yet, with the global world population expected to grow to roughly 9 billion people in 2050 (Andrews, 2015), this model is deemed to be not sustainable (Ellen Mac Arthur Foundation, 2012). Consequently, a transition towards an economy able to decouple economic growth from resource extraction is needed, and an answer for this issue is circular economy, since it pushes the frontiers of sustainability by implementing production systems in which products and materials are used over and over again (Ghisellini et al., 2016; Ellen MacArthur Foundation, 2012; Nasir et al., 2017).

Circular economy can be defined as a restorative- and regenerative-by-design system, because it aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles (Ellen MacArthur Foundation, 2012). In fact, materials are turned into nutrients by enabling a perpetual flow within a biological or technical metabolism, having the potential to remain in a closed-loop system of reuse, refurbishment, remanufacture or recycle activities (Braungart et al., 2007). Three major changes can help the transition towards circular economy. First, energy and material prices are expected to increase in the twenty-first century (Stahel, 2013), making more attractive the recovery of raw materials from products at the end-of-life and hence starting to conceive wastes as resource (Park & Chertow, 2014). Second, new digital technologies (e.g. Internet of Things) are enabling the creation of new business models based on materials traceability (Ellen Macarthur foundation, 2012). Third, the share of green consumers is rapidly growing (Kirchoff et al., 2011). According to the literature, four levers may foster the transition towards circular economy (Lewandowski, 2016; Ellen MacArthur Foundation, 2012), as explained below.

<u>Circular design</u>: in order to be restorative- and regenerative-by-design, circular economy addresses the recovery of materials not only at the end of use. Consequently, companies need to build skills in circular design (De los Rios & Charnley, 2016) to improve product reuse, remanufacturing, and recycling. Some important areas for success in this field are material selection (e.g. mono-material products, or at least components), modular products, standardized components, design for disassembly and design-to-last.

<u>New business models</u>: changing from ownership to usage- and/or performance-based payment models is essential to incentivize companies in design-to-last products. By prioritizing access over ownership, consumers become users and manufacturers retain the goods' ownership, selling the function (solution) instead of the physical product (servitization). In a service economy, materials are treated as capital assets rather than as consumables. Consequently, they are designed for durability or more intensive use (Mont, 2008). The shift from a sales-oriented business model to a function (or solution) oriented one entails the redesign of the product-service system (PSS) adopted. PSSs can be defined as integrated bundles of products and services which aim to create customer utility and value (Boehm & Thomas, 2013). Tukker (Tukker, 2004) identifies three main categories of PSSs:

- product-oriented, where the business model is still mainly geared towards selling products, but some additional services are added (e.g. maintenance contracts);
- use-oriented, where the product's ownership remains with the provider who makes it available in various forms (e.g. through leasing, renting, sharing or product pooling);
- result-oriented, where the client and the provider agree in principle on a result, with no pre-determined product involved (e.g. catering service, pay per use).

Business models based on result-oriented PSSs seem to be the most effective category for shifting to circular economy, because they change the incentive of the manufacturer from maximizing product sales to intensifying the product utilization, with low risk of careless use by the users (Tukker, 2015). More specifically, Linder and Williander (2017) define a circular business model as one in which the logic for value creation is based on the utilization, in the production of new offering, of the economic value retained in products after use (Linder & Williander, 2017).

<u>Reverse cycles</u>: the definition of circular business models entails returning products from users to the producer, involving activities such as reuse/redistribution, repair, remanufacturing, refurbishment and recycling. When feasible, a hierarchy among these activities should be followed: for instance, reuse is preferable to recycling, since much of the value still remains with the product (Park & Chertow, 2014; Sundin et al., 2009). In order to create value from materials after their use, reverse logistics allows the collection of used products. Reverse supply chains are either open- or closed- loop (Genovese et al., 2017): in the first configuration, materials recovered are used in the production of different products, whereas in the second one the function of the reconditioned products remains the same. Generally, recycling operates in open-loop systems, while reuse, remanufacturing and refurbishment activities operate in closed-loop supply chains (Rahman & Subramanian, 2012).

<u>Enablers and system conditions</u>: cross-cycle and cross-sector collaboration, financing, education but especially new disruptive and digital technologies are required, in order to help the circular transition (Ellen MacArthur Foundation, 2012).

2.2 Washing machines

With EU21 market sales between 14 and 15 million units per year for the last ten years (Michel et al., 2015) and an installed base close to 200 million units in 2015 (Europe Economics, 2015), washing machines (WMs) are the most diffused among large home appliances. Given an average sale price of around 400 €/unit (Michel et al., 2015), WMs generate a turnover of around 6 billion € per year. In general, domestic WM can be divided into horizontal and vertical axis, depending on the orientation of the drum rotation axis (Pakula & Stamminger, 2010). More specifically, in order to provide the mechanical action, vertical axis WMs can use an impeller or an agitator (Götz & Tholen, 2016). The average lifespan of a WM is about 10 years (Rüdenauer et al., 2005), but it can vary very sharply based on the number of wash cycles that the machine can perform before breaking down. On average, an entry level WM can perform 2,000 wash cycles, while a premium machine around 10,000 (Ellen MacArthur Foundation, 2012). Over the years between 1970 and 2005, WMs have more than halved the amount of energy consumed per kg of laundry (Stamminger et al., 2005). However, about 10% of households' energy consumption is still connected to washing (Pakula & Stamminger, 2010). Although WMs are typically conceived as standardized products, they may vary widely in weight and composition: a machine weights between 70 to 100 kg, and contains on average more than 20 different materials, encompassing steel, concrete or grey cast iron, carboran plastics, mineral filler, aluminium, EPDM polymers, chipboard, ABS plastics, glass and polypropylene (Rüdenauer et al., 2005). This paper focuses on the WM industry for several reasons. First of all, WMs reflect all the characteristics that make a product suitable for a PSS (Tukker, 2015) since they are relatively expensive, technically advanced, fashion insensitive, used infrequently by customers and requiring maintenance and repair. Moreover, PSSs are the suggested sustainable strategy when the usage phase of a product is predominant (Tukker et al., 2010) and, for WMs, the utilization stage determines more than the 60% of their total cost of ownership TCO (Saccani et al., 2017) and the majority of their environmental impact (Devoldere et al., 2009). Finally, WMs have large chances of environmental improvement, given that current customers' choice is mainly driven by price (Codini et al., 2012) but making customers aware of WMs Life Cycle Costs brings them to opt for machines with, on average, less energy and water consumption (Deutsch, 2010).

3. Circular economy scenarios for WMs

The suggested actions to develop a circular economy scenario for WMs, built around the four levers mentioned in section 2.1, are presented below.

3.1 Circular WM product redesign

In order to keep products, components and materials at their highest utility and value, manufacturers can (1) slow the resource flow through the design of longer-life products or the extension of the product-life, but can also (2) close the resource loop, through the design of products easy to reuse and recycle (Bocken et al., 2016). Consequently, one or more of the following strategies can be chosen:

- design for reliability, which aims to enhance the ability of the WM to perform its function over a longer period of time without failing (Gaiardelli et al., 2008), e.g. through the performance of failure mode and effect analysis (Go et al., 2015);
- design for durability, which aims to develop WMs that will last as long as possible, for instance by designing all components with the same expected life and thus avoiding the discard of the entire WM when only one component fails (Mont, 2008);
- design for serviceability, which aims to enable or facilitate the provision of WM related services during its usage phase, especially maintenance, repair or software and technical upgrading (Gaiardelli et al., 2008), for instance by locating the parts with the highest risk of failure (or requiring upgrade) in easily accessible place;
- design for standardization and compatibility, which encompasses the creation of WMs with parts or components that fit other products as well (Bocken et al., 2016);
- design for disassembly and reassembly, which ensures an easy separation of the WM parts and components, particularly with the aim to make refurbishment, maintenance, remanufacturing and recycling an easier, quicker and cheaper option to waste, e.g. through the reduction of the number of components or separate fasteners (Go et al., 2015);
- design for End-of-Life, which aims to reduce the environmental and the economic impact of the WM End of Life (EOL) and to facilitate its reuse or recycle activities, for instance by manufacturing WM subassemblies with the same or a compatible material (Bocken et al., 2016).

3.2. Establishing new business models: sharing, pay per use-performance, leasing of refurbished WMs

Considering an average utilization of domestic WMs of 165 wash cycles per year (Pakula & Stamminger, 2010), with an average duration of 2 hours per cycle, a WM is utilized less than 4% of its available time. Likewise, considering that an average European household washes around 700 kg of laundry per year (Rüdenauer et al., 2005), the average capacity utilization is around 60% (compared to a theoretical output of 1,155 laundry kg per year obtained multiplying 165 cycles/year with the average load drum capacity, 7 kg/cycle). Combining the two results above, an average WM produces each year a laundry output below 2.5% of its theoretical output. In order to increase this poor utilisation rate, one (large and top quality) WM could be *shared* among various households. For instance, a block of flats could install a common washing area, where WMs could be used by all condominium inhabitants. At present, almost 100% of WMs are sold in a traditional way (Ellen MacArthur Foundation, 2012). However, the ownership of a physical good requires to take it home, install it and maintain it when it breaks down. A new *pay-per-use* or *pay-per-performance* business model can be set up, in which the output generated is billed instead of the product ownership. This approach is commonplace in other sectors, such as business printers and multi-function photocopying machines (Linder & Williander, 2017). To be successful, this approach requires the supplier to provide a full set of services "included in the bill", like consumables (energy, water and detergents) and a full lifecycle service and customer support. Given the low utilization mentioned previously, WMs are still available for use after 10 years in operation and hence parts or entire products could be reused. Unfortunately, it is acknowledged that in the European market, while 30-40% of end-of-life WMs is collected, not more than 10% of them gets refurbished (Ellen MacArthur Foundation, 2012). As an alternative, a top quality WM could be *leased*, following the pay per use scheme, for 4 sequential 5 years terms. After each term, the machine could be reconditioned by checking and changing the worn-out components and upgrading the control firmware with the latest version, in a way to incorporate up-to-date energy and water saving washing programs.

3.3. Reverse cycles: supply chain redesign

The actions described in 3.2 require a redesign of the WM supply chain, in order to facilitate and encourage the return of products from the user to the manufacturer. To do so, three main processes must be established (Koppius et al., 2014): the (1) acquisition process, in order to collect the right volumes of products or materials of the right quality and for a reasonable price, the (2) recovery process, which aims to refurbish, remanufacture or, at least, recycle the products and materials collected and the (3) remarketing process, in order to find markets that want to buy the recovered products. Moreover, also spare logistics can be redesigned, given demand lumpiness and point of use geographical dispersion. Harnessing big data and related analytics (see 3.4) together with more focused logistics tools can sharply increase the spare parts supply chain's efficiency and effectiveness. These tools could be:

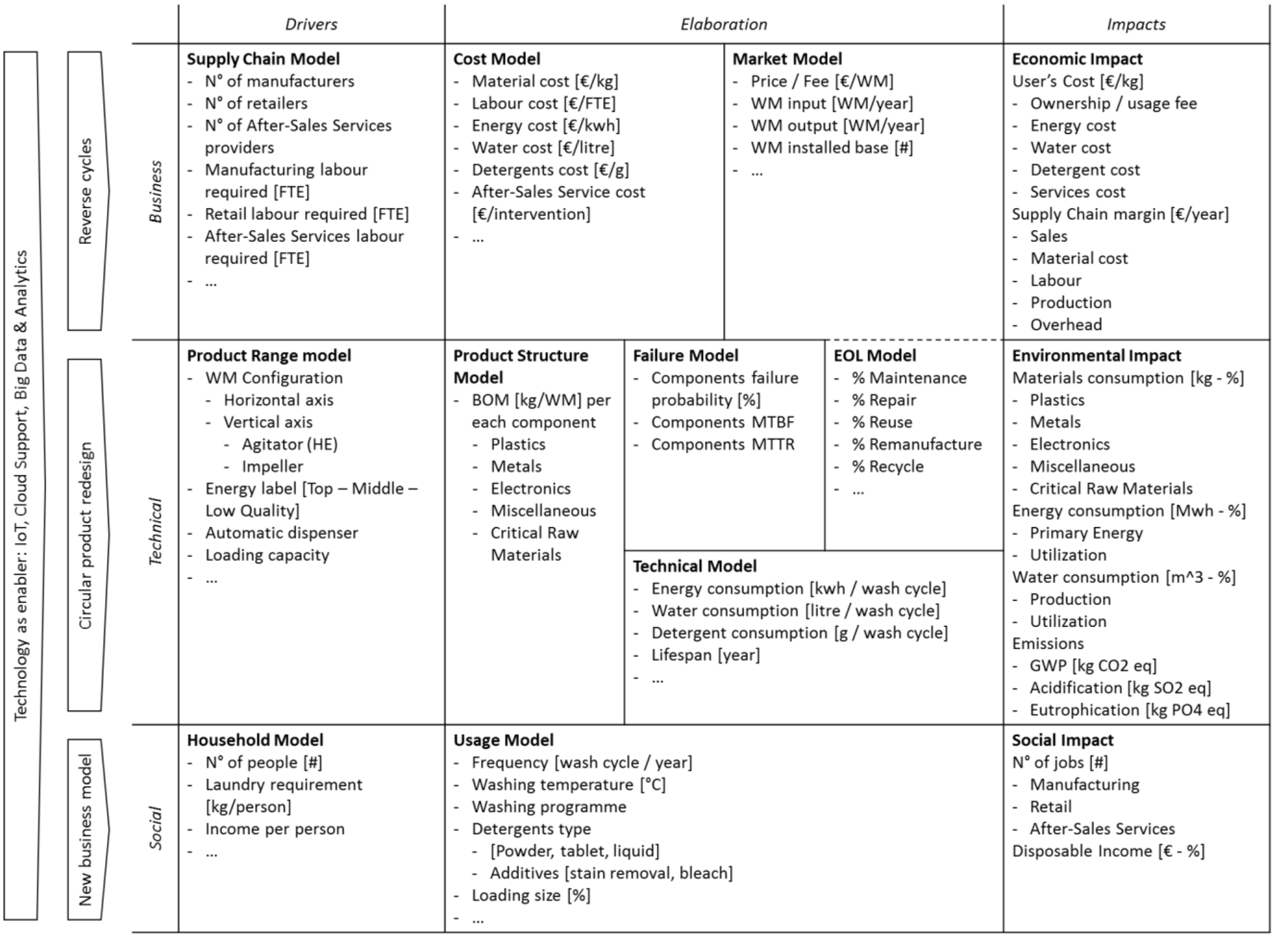
- spares classification, which aims to identify different classes that should be planned in a customized way (Bacchetti & Saccani, 2012);
- spares demand planning and forecasting, which could be obtained by extrapolating data from past demand dataset (Syntetos & Boylan, 2006);
- spares geo-localization and stock in transit planning, which enables the monitoring of spares in each supply chain tier and enhances the planning of spares-in-transit, especially through algorithmic approaches like (Saccani et al., 2017b).

3.4. Technology as enabler: Internet of Things, Cloud support, Big data & analytics

WMs and other white goods are typically conceived as static pieces of stand-alone hardware. However, the *Internet of Things* (IoT) (Kortuem et al., 2010) allows several opportunities such as diagnostic data generation, remote control and service, single user access, metering, payment and firmware updating. Moreover, the current way to support WMs in field is through a (direct or indirect) network of service providers. By generating and sharing in the *cloud* the analytic machine technical data, a community of professional repairman can be established. Thus, when a failure occurs, users or directly machines can place a service request in the net and, after the intervention, the service quality of the involved repairman could be rated by the user through an appropriate platform. This community could encompass both professionals as well as part-time practitioners with appropriate competence, increasing the job opportunities e.g. for workforce previously active as blue collars in manufacturing firms that have laid them off. Once a large amount of smart and connected WMs is in operation, a vast volume of data will be generated, regarding machine type, location, utilization and functioning status, diagnostic data, metering of main consumables (energy, water, or detergents), login access and usage by single users and their respective bills. These data should be stored in an appropriate data repository in the cloud, from where they can be retrieved in order to support the development of predictive *analytics*, for instance to forecast the future statuses of the WMs, and consequently the future needs of maintenance and repair activities, as well as spare parts.

4. Assessing circular economy scenarios in the WM industry: the proposed framework

According to the findings of the literature review carried out in section 2, the conceptual framework depicted in Figure 1 was developed. The overall aim is to support static simulation processes where different circular economy scenarios (see section 3) can be assessed and compared with the current setting, following the comparison of the measures grouped under the "Impacts" column. These measures were identified thanks to a literature analysis of both scientific and "grey" literature regarding WMs studies. More specifically, these impacts were divided into three categories, following the triple bottom line scheme: the economic measures cover the customer/user perspective by using a TCO approach (Saccani et al., 2017) and the margin of each actor of the WM supply chain; the environmental impacts comprise the materials, energy and water consumption (in each life cycle stage) as well as the main emissions to air (Rüdenauer et al., 2005); the social indicators include estimates regarding the number of jobs (in each tier of the supply chain) and the disposable income per household (O'Connell et al., 2013). In order to assess all these indicators, the main elements which characterize the WM industry were grouped into 10 different but interrelated models. Aspects such as the configuration of the supply chain, the WM typology and the type of user (i.e. household) represent the *drivers* (first column) of the overall framework, providing input for the *elaboration* of the other models. Moreover, Figure 1 depicts the relation between the WM industry and the four circular economy levers: the reverse cycle lever affects mainly the *business* aspects, modifying the configuration of the supply chain; the circular product redesign affects mainly the *technical* aspects, changing the WM product itself; the business model lever provides new form of production and consumption, affecting mainly the *social* aspects and thus the household habits. Finally, the digital technology levers are conceived as enabler of all the others elements.



Technology as enabler: IoT, Cloud Support, Big Data & Analytics

Reverse cycles

Circular product redesign

New business model

	Drivers	Elaboration				Impacts
Business	**Supply Chain Model** - N° of manufacturers - N° of retailers - N° of After-Sales Services providers - Manufacturing labour required [FTE] - Retail labour required [FTE] - After-Sales Services labour required [FTE] - …	**Cost Model** - Material cost [€/kg] - Labour cost [€/FTE] - Energy cost [€/kwh] - Water cost [€/litre] - Detergents cost [€/g] - After-Sales Service cost [€/intervention] - …	**Market Model** - Price / Fee [€/WM] - WM input [WM/year] - WM output [WM/year] - WM installed base [#] - …			**Economic Impact** User’s Cost [€/kg] - Ownership / usage fee - Energy cost - Water cost - Detergent cost - Services cost Supply Chain margin [€/year] - Sales - Material cost - Labour - Production - Overhead
Technical	**Product Range model** - WM Configuration - Horizontal axis - Vertical axis - Agitator (HE) - Impeller - Energy label [Top – Middle – Low Quality] - Automatic dispenser - Loading capacity - …	**Product Structure Model** - BOM [kg/WM] per each component - Plastics - Metals - Electronics - Miscellaneous - Critical Raw Materials	**Failure Model** - Components failure probability [%] - Components MTBF - Components MTTR	**EOL Model** - % Maintenance - % Repair - % Reuse - % Remanufacture - % Recycle - …		**Environmental Impact** Materials consumption [kg - %] - Plastics - Metals - Electronics - Miscellaneous - Critical Raw Materials Energy consumption [Mwh - %] - Primary Energy - Utilization Water consumption [m^3 - %] - Production - Utilization Emissions - GWP [kg CO2 eq] - Acidification [kg SO2 eq] - Eutrophication [kg PO4 eq]
			Technical Model - Energy consumption [kwh / wash cycle] - Water consumption [litre / wash cycle] - Detergent consumption [g / wash cycle] - Lifespan [year] - …			
Social	**Household Model** - N° of people [#] - Laundry requirement [kg/person] - Income per person - …	**Usage Model** - Frequency [wash cycle / year] - Washing temperature [°C] - Washing programme - Detergents type - [Powder, tablet, liquid] - Additives [stain removal, bleach] - Loading size [%] - …				**Social Impact** N° of jobs [#] - Manufacturing - Retail - After-Sales Services Disposable Income [€ - %]

Figure 1: the framework for assessing circular economy scenarios in the WM industry

5. Results and discussion

In order to develop a circular economy scenario, the actions envisaged in Section 3 should not be considered individually, since major benefits come from a combination of them (Ellen MacArthur Foundation, 2012). For instance, the IoT technology can enable a pay-per-performance business model where the manufacturer leases top quality WMs and retains their ownership. Thus, the manufacturer has the incentive to design long lasting and highly efficient products and to collect them when they reach the end of use. Although several scenarios are possible, this paper tries to give a preliminary idea about how the simulation process supported by the framework works. Thus, few among the impacts described above are roughly estimated hereafter, based on preliminary data. In the “IoT – pay-per-performance” scenario, households can indirectly benefit from (1) a reduction of the energy and water cost, while environment and society as a whole can benefit from (2) total savings in energy and water consumption during the utilization phase of the WMs. The expected impact of these benefits was estimated for Germany, France, United Kingdom and Italy, since these four countries account for nearly 60% of the European household WM installed base (Pakula & Stamminger, 2010). Table 1 and Table 2 summarize respectively an educated guess of the electricity and water data for the current installed stock – based on (Pakula & Stamminger, 2010) – and for the average best in class WM, based on (Josephy et al., 2015), that a hypothetical dealer could provide to households under a pay per performance scheme. Some adjustments were made to take into account the country average household size (Eurostat, 2016a).

Table 1: detail of the WM electricity consumption

Country	Frequency Wash cycles / year	Current scenario kwh/wash cycle	Best in class scenario kwh/wash cycle	Energy price* €/kwh
Germany	160	0.87	0.45	0.295
France	165	0.94	0.45	0.165
UK	165	1.14	0.45	0.215
Italy	170	1.05	0.45	0.245

*(Eurostat, 2016b)

Table 2: detail of the WM water consumption

Country	Frequency Wash cycles / year	Current scenario Litre/wash cycle	Best in class scenario Litre/wash cycle	Water price* €/m^3
Germany	160	57	45	2.26
France	165	60	45	2.16
UK	165	60	45	1.63
Italy	170	63	45	0.40

*(Conroy, 2013)

From a single household point of view, the estimates project a yearly saving ranging from 18.5% in France, where the electricity price is considerably lower than other countries, up to 40% in the case of Germany (Table 3). On average, households can reduce their energy and water cost by almost 30%. From a national point of view, moving towards a circular scenario allows, under the condition that all households have chosen the new business model, to a total energy saving of almost 9.4 terawatt hour per year. This figure accounts for around 0.62% of the total electricity generated in 2014 in these countries (Eurostat, 2016c), reducing the pressure on non-renewable sources (e.g. oil, carbon, gas) used for the electricity generation, in a way that depends on the country energy mix. Moreover, the total water saving can amount to 0.26 cubic kilometres per year, about 1% of the total water abstraction for public water supply of the selected countries (Eurostat, 2016d). These results, detailed for each country, are depicted in Table 4.

Table 3: Yearly saving for a single household

Country	Current energy and water cost	Best in class energy and water cost	Single household saving
	€/year	€/year	%
Germany	61.68	37.51	39.2
France	34.72	28.29	18.5
UK	40.61	28.07	30.9
Italy	29.27	21.80	25.5

Table 4: total energy and water saving

Country	Number of WMs	Energy saving (utilization)	Share of the energy generation	Water saving (utilization)	Share of the water abstraction
	x 1000	Twh/year	%	Km^3/year	%
Germany	37,166	2.50	0.49	0.071	1.40
France	23,787	1.92	0.47	0.059	1.07
UK	23,775	2.71	0.89	0.059	1.01
Italy	22,145	2.26	0.80	0.068	072

6. Conclusion and future research directions

This paper provides a new systemic framework, which aims to support static simulation processes and thus to assess and quantify the economic, environmental and social impacts of circular economy scenarios in the WM sector. An estimation of some relevant impacts is also carried out. These results contribute to bridge the lack of knowledge and reduce the uncertainty that characterizes circular economy, at least for this particular case, helping stakeholders to start the transition towards more circular scenarios. For instance, WM manufacturers may use the information about the washing cost savings in order to define the pay per performance fee in a PSS offering. Moreover, policy makers may use the total energy and water savings estimate in order to set supportive incentives and legislation. However, all the figures reported above are based on reasonable but still preliminary assumptions, and thus can provide only approximate information. Furthermore, aspects such as the relation between all the elements depicted in Figure 1 (for instances the relation between wash cost, drum capacity, WM load size and consumer habits) have not been fully considered yet and, therefore, need to be addressed in depth by this research programme. Thus, the next steps of our research will address the detailed modelling of the mathematical calculations and relations underlying each elements of the framework and the collection of the data needed to feed it. The entire project will add to current research since the quantification of impacts and circular scenario (what-if analysis) is pursued adopting a holistic and systemic approach, that allows to avoid rebound effects by applying systemic thinking, according to circular economy principles (Ellen MacArthur foundation, 2012).

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