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System analysis including aspects of governmental policies, business models and product/service design

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Abstract

For today's transformation towards a circular and resource-efficient economy, an understanding is needed of how changes in socio-technical systems affect resource efficiency (RE). This paper suggests an approach to analyse the RE of socio-technical systems and the related Product-Service Systems (PSSs). A conceptual framework consisting of elements of business models, governmental policies and product and service design is developed. Laundry practices in Sweden serve as the context for a case study. The results indicate that asset sharing is most resource-efficient to facilitate domestic laundry practices, followed by PSSs and individual ownership coming last. This type of analysis helps to understand the role of PSS for RE. Future research focuses on dynamic modelling of socio-technical systems and their impact on RE.

Keywords: Resource Efficiency; Business Models; Governmental Policies; Product and Service Design; Product-Service Systems;

1. Introduction

The transformation into a circular and resource-efficient economy is a major objective for the European Union [1, 2]. Product Service Systems (PSSs) potentially play a significant role in this transformation [3]. In order to make the right decisions toward a circular economy (CE), we need a methodology that helps to understand how changes in socio-technical systems affect resource efficiency (RE).

Look at a car, for example. There is a common understanding that for assessing its RE, a lifecycle perspective is necessary. Yet, if we consider changes over time, we find that the resource use depends on many factors external to the car as a system and its supply chain. Over time user behaviour, regulations, and the offerings change significantly. The oil shocks of the 70s and 80s were disruptive in many ways. In some emergencies, the supply of fuel was so limited that people could drive only on given weekdays [4]. Scarcity made fuel-efficient cars more appealing. In addition, environmental concerns raised requirements for car engines over time. People's attitudes towards car ownership also changed over the last decades [5]. Owning a car used to be a prime status symbol; today, enabled through new business models, many turn from car owners into car users. Even more, imagine the repercussions of an autonomous self-driving car on the value of driving and the additional kilometres driven with the same costs. Many of the system aspects in the automotive sector that are affecting RE change over time.

We hypothesise that these systemic aspects and their interlinkages are relevant to understanding the RE of a socio-technical system. Relevant system aspects could be grouped into governmental policies (GPs), business models (BMs) and product and service design (PSD). GPs frame the rules of the game. Specific to each case, they shape markets through subsidies and taxes, affect technologies by bans and requirements, or nudge people to the desired behaviour in various ways. BMs guide the ways companies create, capture and deliver value. BMs are treated here in a stylised way and are relevant as far as they can be expected to affect RE, e.g., the difference between car-pooling and car ownership by

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number of cars needed to cover mobility needs. PSDs determine the RE of products and services in a direct way. Major strategies to improve product-related RE are designing longer-lasting products, modularisation and remanufacturing, component reuse or designs with fewer materials [6].

It has been acknowledged before that for a CE new BMs, new PSDs and new GPs are necessary [7]. Yet, being able to understand how GPs, BMs and PSDs interact and affect system behaviour is crucial, as well as how it improves the overall effectiveness of any measure. Therefore, these three "spheres of influence" and the multidimensional cause-effect relations between them are at the core of this analysis. We can see previous attempts where dynamic modelling methodologies served to get a better understanding of systems' behaviour and an improved assessment of the resources used. Stasinopoulus et al. [8] integrate life-cycle analysis and dynamic modelling. By using a wide system scope and including recycling markets and long-term developments, material selection for car body-in-whites could be improved and energy use decreased. Wu *et al.* [9] apply agent-based modelling in order to add behavioural components to a life-cycle sustainability assessment (LCSA) on green building development. Their simulations lead to a better understanding of building practices for given incentive structures. Dace [10] simulate interlinkages between governmental policies, the market, and a waste management system, as well as behavioural and ecological aspects. The results inform about taxes for higher material RE in the waste management system in Latvia. Onat *et al.* [11] apply a macro level scope, where they conduct an LCSA through dynamic modelling. The model combines macro variables like gross domestic product, population size, public welfare and climate change with individual transportation; the simulation results show how the variables' interlinkages affect the overall emissions. All of these papers [8-11] broaden the scope of a traditional RE assessment and try to simulate the interlinkages of the system under study with other systems.

We claim there is a lack of knowledge to which degree these three affect the RE of a socio-technical system. Thus, we ask the following research questions:

RQ1: *How do GPs, BMs and PSDs affect the RE of a socio-technical system?*

RQ2: *How does the approach of focusing on GP, BM and PSD aspects help in analysing the role of the PSS for RE?*

The next section locates this work in the existing literature on RE assessment, while Section 3 quickly outlines the applied methodology. Section 4 then describes the conceptual framework. Section 5 continues by outlining the case study on laundry practices, which is followed by results and discussion in Section 6 and 7 and finally, the conclusion in Section 8.

2. Resource efficiency assessments

CE is an economic system that aims to minimises the usage of virgin materials and overall emissions by keeping resources in technical and biological cycles [12]; RE is one of its building blocks. Generally, RE is about meeting society's needs with less material consumption [13]. On the product level, it is about reducing the resources necessary to provide a unit of product or service. According to the United Nations Environment Programme, resources are "*naturally occurring assets that provide use benefits through the provision of raw materials and energy used in economic activity*" [13]. Efficiency is measured either as the relation of useful outputs over inputs or in an eco-efficiency manner as useful outputs over environmental impacts [14].

RE indicators can be distinguished by their scope – (gate-to-gate, life cycle, domestic or global) or by the type of efficiency measured. The multitude of indicators includes ways to measure economic, ecological and social RE [15]. Yet, this work focuses on environmental RE. RE indicators belong to a larger family of tools. There is an understanding that sustainability-oriented research follows the idea of the holistic analysis, looking beyond one discipline to consider all that is relevant. It brings together economic, environmental and social aspects. Over the last few decades, a plethora of sustainability assessment (SA) tools has emerged that try to assess the sustainability of various objects of study. SAs typically deal with policies, projects, organisations, products and services or substances. Among others the SA methodology includes methods like material flow accounting, environmental impact assessments, LCA, life-cycle costing, cost-benefit analysis, input-output analysis or LCSA [16, 17]. Yet, it seems that the static reductionist character of these approaches is not appropriate for understanding system behaviour. Halog [17] writes in relation to this that "*we have forgotten to include the trans/cross-boundary impacts or interrelationships between and among the parts. We forgot to realize that the whole is not really equal to the sum of the parts when considering the interconnections between sub-systems of our global society*".

3. Research methodology

The "socio-technical system" is assumed to be most suitable for the level of analysis. Here, the term refers to the network of abstract and concrete concepts that are part of the provision of a given product or service.

Laundry practices in Sweden serve as the case study context. The socio-technical system around laundry practices has the washing machine at its centre and spans from users to manufacturers and policymakers. Due to their importance to everybody's lives, technological character and relatively high resource usage, laundry practices are an area with decades of academic analysis. Peer-reviewed academic literature, as well as grey literature, were analysed in order to collect important aspects regarding GPs, BMs and PSD. The limited space of the conference publication does not allow an elaborated analysis. Yet, three scenarios were developed in order to show the impacts of GPs, BMs and PSD in a stylised fashion.

4. Conceptual framework

For this study a conceptual framework consisting of BM-, GP- and PSD-elements is developed according to [18].

4.1. Design of Products and Services

The design of products and services has a direct influence on the materials used, the use phase and the end-of-life. Focusing on CE, circular design requires keeping resources within technological or biological cycles [19]. This may be achieved by designing products for long-life or design for product-life extension, i.e. reuse, repair refurbishing or remanufacturing [20].

4.2. Business models

A BM guides how a company creates, captures and delivers value [21]. CE BMs are fulfilling the same functions as conventional BMs but in a more resource-efficient fashion. CE BMs may be grouped as follows [20]:

Access and performance models: provision of a service or function instead of a physical product.

Extending product value: exploitation of residual product value and maintaining the utility of products by feeding them back into production after use through activities like refurbishment or remanufacturing [22].

Classic long-life model: designing products with long lifetimes, through design for durability and repair. For products that consume resources during the use phase, it may be more beneficial to replace them earlier [23].

Encourage sufficiency: BMs based on the reduction of end-user consumption. There are high service and quality brands that encourage their customers to actually buy less.

Extending resource value: collecting and turning materials to new purposes originally meant for waste.

Industrial symbiosis: BMs that facilitate the use of outputs of some processes as inputs for others, between companies that are in geographical proximity.

4.3. Governmental policies

The European Union (EU) has developed an increasing number of policies to address environmental issues throughout product life cycles. A recent one is "Closing the loop – an EU action plan for the Circular Economy". The action plan distinguishes between actions on production, consumption and waste management. Priority areas are plastics, food waste, critical raw materials, construction and demolition, biomass and bio-based products and innovation and investments [1]. The CE Action plan is only part of an initiative addressing RE. Other strategies focus on sustainable use of natural resources, sustainable consumption and production as well as prevention and recycling of waste [24].

Relevant regulations can be divided into three main categories: making products more energy efficient, banning hazardous substances, and making sure products are disposed of in an appropriate way at the end-of-life. Other interests in the field lie in setting standards that promote durability, RE, and reuse at the EU level [25]. These mandatory EU rules are complemented by various other instruments, such as mandatory and voluntary labelling schemes and public procurement, which are mainly applied at the national level [25]. While the EU is often leading the way in product policies, other jurisdictions such as the US, Japan and China have also introduced progressive policies [26].

5. Case study: household laundry practices

5.1. Laundry-related business models

The dominant BM in the washing machine (WM) industry is sales-based. Customers are purchasing machines and use them for a given time before disposing of them. Service-based BMs are not new to the laundry market either. Commercial laundry services have existed around the world for decades [27]. For this paper, however, only BMs that are applicable to laundry practices of the broader population are interesting. Two recent examples of particularly service-based BMs are BlueMovement [28] and Homie [29]. Both belong to the CE BM group of access and performance models. BlueMovement is a leasing-based PSS, limited to a maximum six-year term of lease, after which the machines are returned and potentially reused. Homie is a pay-per-use model with pricing depending on the degree of sustainability of the washing behaviour; a cold wash costs 1.13 €, a 40 °C wash 1.31 € and a 90 °C wash 1.69 €. Such service-based offerings have shown success in facilitating sustainable behaviour [30]. Currently, service-based offerings seem to be based on conventional machines, the design adaptations apparently do not exceed the level of conventional product-based PSSs, and adaptations are mostly aimed at service and less on product aspects.

A different type of laundry-related BMs are systems that facilitate the sharing of WMs. This form of asset pooling provides households with the possibility to share WMs in a facility outside one's flat instead of having the need to own one [31, 32]. The relevant examples are communal laundry rooms and launderettes; both are access-based BMs. Launderettes are self-service laundry businesses, distinctive through the coin toss payment. The machines have a long-life and high durability, and users do not own the machines but only use their cleaning function. Communal laundry rooms are facilities that are shared by the tenants of a building of flats and are managed by the housing companies. Payments are usually included in the rent, and access to the facilities is free but limited. A third and rather theoretical option for sharing WMs commercially is peer-to-peer rental, which will not be covered here.

5.2. Laundry-related policies

According to the International Energy Agency [33], 80 countries have implemented energy efficiency policies such as minimum energy performance standards, labelling, education or top runner approaches that drive energy innovations and efficiency gains in appliances and equipment. In the EU, average annual efficiency improvements of 2.1% have been achieved for washing machines in the past decades [33]. Such policies are setting the direction in the long run affecting PSD and BMs. Other GPs affecting BM decisions or PSD towards RE are result-oriented procurement contracts, ambitious public procurement tenders, and top runner approaches.

In the EU, WMs are subject to an array of directives. The Ecodesign directive puts pressure on producers to improve the environmental performance of household appliances like washing machines. The energy labelling directive [34] forces producers to inform customers regarding the environmental performance of products based on an efficiency scale from A-G. It motivates producers to design products complying with energy performance levels, and it appeals to customers and makes it easier for their environmental awareness to be part of purchasing [35]. The labelling, as well as banning of substandard models (less than A), has shown success. A customer study shows that already three years after the labelling scheme became compulsory, the machines of top efficiency class had the highest share of sales (43%) [36].

Washing temperature is a WM's main leverage to decrease electrical energy use over the lifecycle [37]. Current policies accommodate that by requiring new washing machines to have at least one washing programme running at 20 °C [38].

Taking a national example of laundry-related policies, Swedish building regulations foresee to have communal laundry rooms for tenants in multi-dwelling buildings. Yet, Borg and Högberg [39] raise awareness of current trends away from communal laundry rooms in new multi-dwelling buildings towards a WM for each household. In Sweden, in the 1950s and 60s communal laundry rooms were a regular part of multi-family building plans. In this period, 80%-90% of households in multi-family buildings had access to communal laundry rooms. A study from 2006 suggests that 75% of the total population had access to their own WM and about one-third of people living in multi-family buildings use their own machine [40].

5.3. Laundry-related product design

The average lifespan of washing machines differs between studies. A washing machine is used roughly for 200 wash cycles a year and for a lifetime of around 10 – 15 years [41, 42]. Multiple components have a longer theoretical lifespan than the WM itself, e.g., the brushless DC motor, the weights or the steel frame. Remanufacturing processes are more economically feasible through service-based offerings in which uncertainties regarding quality and quantity of returned cores are diminished and where high-quality components have several lifetimes [43]. Design for dis- or reassembly is not common in the customer WM industry. Design for ease of maintenance and repair can be observed in limited ways [44].

WM producers simulate a given use period through accelerated life test procedures. A full product lifetime is simulated through non-stop usage of WMs over a given period [45]. The wear and tear of a WM depends less on age than on usage, and thus it makes sense to refer to lifespan in terms of wash cycles instead of years. According to the Sinner's circle, a wash result depends on washing time, mechanical work, wash temperature and the chemical application [46]. For achieving similar wash results, trade-offs are possible, i.e., a longer wash with lower temperatures, stronger detergents with lower temperature, etc.

In a study across eleven EU countries, researchers determined the average wash temperature to be 42.3 °C [47]. In a comparable context, recent corporate campaigns including education and behavioural nudging have resulted in a reduction of washing temperature down to 40.9 °C [48]. Remarkably, washing at 20 °C uses up to 70% less electricity compared to a 60 °C cycle [47]. Stamminger [49] calculates that a temperature increase by 1 °C leads to an increase in energy use of 0.022 kWh.

The product designs of privately-used WMs and professional WMs differ significantly by durability, load capacity, energy efficiency, programme selection, weight, etc. Retail WMs have a lifespan of approximately 2,200 cycles while professional ones can have up to 30,000 cycles. Professional machines are significantly heavier (e.g. [50]).

5.4. Scenario setting

Three stylised scenarios are defined: *individualistic*, *sharing* and *PSS* (Table 1). The scenario population equals the actual number of Swedish households located in multi-dwelling buildings, which is around 2.5 million. Multi-dwelling residents are likely in a decision situation whether to have their own washing machine, share one or to use a service for the household laundry, whereas residents of detached housing have, to a great majority, access to their own washing machine. A wash cycle contains 7 kg of laundry, only front load washers are considered.

The individualistic scenario has all the 2.5 million households owning a WM (e.g. [42, 51]). The households use on average 3.9 washing cycles [47], á 2 hours per week which equals 7.8 hours a week and a utilisation of 7.8/24 or ~5%.

In the sharing scenario, no single household owns a WM individually. Based on Swedish industry recommendations [39], we assume that on average 15 households are sharing a WM. This results in 167,000 WMs needed to cover the laundry needs of the population. Given the same number of 3.9 wash cycles per week and limited access of 16 hours per day, the utilisation rate is 16/24 or 66%. The semi-commercial WMs used in this scenario (e.g.[50]) have a relatively long lifespan of 30,000 cycles.

The third scenario embraces PSS and reflects a middle way of theoretically supplying each household with service-based contracts. Following previous examples of this conference [52, 53], this scenario is rather hypothetical. The convenience and accessibility are the same as if purchasing a WM. It is assumed that in terms of energy and material usage, PSSs lie between the individualistic and the sharing scenarios. Therefore, energy use is 0.75 kWh per cycle, and the material use per machine lies at 100 kg. Although offerings such as BlueMovement or Homie exist on the market, a case of PSS designs different from a typical product-based PSS with warranty and guarantee are not reported. Yet, it is assumed that for a PSS, durability and maintainability are key aspects as they are saving costs for manufacturers. Given weight and space restrictions, the lifespan is set to be between the private and the semi-professional machines at 15,000 cycles. Ownership will be of a temporal form (rental or leasing). Utilisation stays like in the individualistic scenario at 5%.

6. Results

The data can be divided into input and output. The input is comprised of the basic parameters that express BMs and PSD aspects, whereas the GP effects are shown indirectly. The outputs inform about the necessary *number of WMs* to cover laundry needs, the embodied *material in stock* of the WMs, and a *replacement* rate that indicates the stock replacement time which is relevant for long-term considerations. *Utilisation* is not just affecting the number of WMs necessary but also the wear-out of the WMs. Therefore, *lifespan* differs dramatically between the scenarios. *Material* and *energy use* are taken from exemplary WMs (e.g., [50, 51]). A WM's mass is used as indicator for material use. As mentioned before, the *energy use* of laundry practices depends mainly on the temperature. The total energy use of the three scenarios are in the same relation as the individual machine levels, as equal numbers of cycles are assumed.

The *number of machines* shows that in the sharing scenario, only a fraction of WMs is necessary to provide laundry services. In terms of material use, the sharing scenario is beneficial, independent of the timescale. The *material in stock* describes how much material is embodied in the total number of WMs. The individualistic scenario has 2.5 million x 71 kg = 177.5 kT of material, the sharing scenario 25.7 kT, and the PSS scenario 250 kT. Calculations combining *lifespan,* the number of wash cycles of a population (for sharing: (0.17 million x 30,000 cycles) / (2.5 million x 3.9 cycles/week) = 514 weeks and *utilisation* calculations show that the whole stock is replaced after 514 weeks in the sharing, 564 weeks in the individualistic, and 3,846 weeks in the PSS scenario.

Table 1: Overview of the individualistic, sharing and PSS scenarios

Model variable	Individ.	Sharing	PSS
Inputs			
Private ownership [%]	100	0	100
Utilisation [%]	5	66	5
Lifespan [cycle]	2,200	30,000	15,000
Energy use [kWh/cycle]	1	0.45	0.75
Material use [kg/WM]	71	154	100
Outputs			
Number of WMs [million]	2.5	0.167	2.5
Material in stock [t]	177,500	25,700	250,000
Replacement [week]	564	514	3,846

7. Discussion

Table 1 offers a few answers how GPs, BMs and PSD affect the RE of laundry practices. It shows that PSSs offer advantages compared to the individualistic scenario and disadvantages when compared to the sharing scenario. The advantages stem from a longer lifespan, the disadvantage from the relatively low utilisation.

Noteworthy is that s*haring* and *PSS* bear additional material savings potential as reuse, refurbish and remanufacturing can be organised easier when ownership is not transferred to the user.

Considering long lifespans, it needs to be said that long-lasting products are not always ecologically beneficial as efficiency advances may outweigh production impacts [54].

Sharing products or pooling assets decreases the number of units necessary to fulfil people's needs [32], an effect that has been seen in car-sharing systems as well [55]. The differences in material use and material in stock put the sharing scenario into the best light.

Regarding RQ2, this paper's approach is useful to inform about the general role of PSS for RE; utilisation and lifespan are identified as two key parameters. Although, it has been remarked before that PSS-based BMs do not necessarily lead to resource efficient solutions [3], this rough assessment shows that PSS is superior to a sales based model. As mentioned earlier, due to the lack of existing result-oriented PSD for laundry practice in common households the PSS scenario was located between the other two extremes.

The role of GPs is not obvious in Table 1. Yet, the entire idea of the sharing scenario goes back to a Swedish policy requiring building developers to offer communal laundry facilities to tenants [39]. This policy was an attempt to ensure the right to cleanliness for everybody as well as relieve women, who traditionally took care of laundry, from this once time-consuming chore [56]. Other GPs take time to show effect. Minimum energy performance standards or the effect of labelling [33] change the overall machine stocks gradually.

8. Conclusion and future steps

This paper combines aspects from the areas of business models, governmental policies and product and service design and their impacts on the RE aspects of socio-technical systems. A literature review and a case study have been conducted. Unlike previous conference contributions that focused mainly on the conceptualisations of PSSs in the washing machine industry [52, 53], this paper also assesses RE aspects.

Scenarios cover a range of aspects from PSS to sharing economy. The results show a mixed picture of the potential of PSSs for RE in common laundry practices. Managers interested into resource efficiency may find this type of analysis useful for business model considerations.

This paper sets the stage for future research. In the next steps, we will look into more detail at the dynamics of the washing machine industry. By dynamically modelling the stocks and flows of the system a better understanding of resource usage problem of laundry practices is expected.

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