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From Goods to Services: The Life Cycle Assessment Perspective

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ABSTRACT

The traditional good dominant logic framework was recently replaced by a service dominant logic. This shift requires also different perspective on life cycle assessment (LCA), from the definition of the value of the process to be analyzed and thus the reference scenario, to the measures to be generated in order to accurately and reliably present the environmental, social and economic impacts. Moreover, it requires to interpret differently the input-output inventory of physical resources of materials and energies, but also to stress the importance of assessing non-physical resources like effort and knowledge. In general, moving from a good to a service or a product-service system, changes the focus from production to usage, identifying by different alternatives, which dematerialize the demand by servicizing. In addition, servicizing increases the level of the life cycle's value, where eventually the customer could be turned into a provider and reduce the environmental impacts. In service based LCA perspective, the joint value co-creation and the customer behavior are the main drivers of the LCA impacts due to the promotion of a general functional unit that fulfill the need. Three cases of study are used as examples to apply LCA to the transition from goods to services.

KEYWORDS

Life cycle assessment, Sustainability, Service dominant logic, Product service systems, Servicizing

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1. INTRODUCTION

The biological concept of life cycle, which accounts for the series of stages that an organism passes from birth to reproduction and generation of an offspring, was borrowed to many other fields. Examples include manufacturing and management, representing a series of stages through which not only the individuals of a society but the requested essential living demanded products and its corresponding processes, in terms of goods or services, pass during its lifetime (Klöpffer 1997; Guinee 2002). In many of these areas, resources and emissions inventories are employed to analyze the external effects of each life cycle's stage in the context of the whole life cycle. This way, it is possible to improve the efficiency and the effectiveness of the product, the process or the service in environmental terms. In general, this input-output balance is referred to the involved streams: resources such as materials, energy, water and land and environmental burdens to the air, water and soil.

In the case of production processes, a set of physical resources can be allocated not only to the main units or equipments such as assembling lines or reactors but to the facilities that contain them and their use and maintenance: warehouses, workshops, heating, lightning, etc. The environmental burdens of each of those stages can be measured with respect to economic (e.g., profit or contribution to economic growth), social (e.g., well-being or equity) and environmental (e.g., human health, greenhouse gas emissions) metrics. Regarding these metrics, an excellent selection of proper sustainability metrics for the process industry was discussed a decade ago (IChemE 2002), and we used this approach in cases of study during the last years (Dominguez-Ramos et al. 2015; Margallo et al. 2015; Garcia-Herrero et al. 2016). Other standards are also available: the way in which the measurements can be reported in the case of companies is usually completed according to the Global Reporting Initiatives standards (Global Reporting Initiative 2018). Nevertheless, apart from the physical resources, there is another set of resources, which barely has been discussed and that corresponds to the non-physical ones. These resources must be also allocated to each of the life cycle's stages, which includes effort, time and manpower, and information and knowledge.

2. LIFE CYCLE ASSESSMENT (LCA)

From a goods dominant perspective, the life cycle of a process, product or service is typically composed of the following stages: extraction of raw materials, manufacture, distribution, use and end of life, from cradle to grave (i.e., from birth to disposal) or from cradle to cradle (i.e., from the beginning of life to reuse, recycling or recovery) (Wolfson 2016). Due to the efforts in this field through decades, the Life Cycle Analysis or Assessment (LCA) is nowadays a well-known tool to manage and to improve the environmental performance of processes, products or services, and also to compare between alternatives that share the functional unit (Day 1981; Klöpffer 1997; Guinee 2002; Fredga and Mäler 2010). In addition, environmental metrics are generated to quantify the potential impacts, for instance carbon footprint (i.e., the overall emission of greenhouse gases) or water footprint (i.e., the overall use of water) (Cucek et al. 2012). These metrics are used to identify the life cycle's stages that can be improved, by decreasing the use of non-renewable natural resources and individual emissions to the three environmental compartments. As a result, the environmental burdens are assessed so it is possible to identify hot-spots, increasing the efficiency of the whole life cycle, and also searching for replacements in the form of more benign options.

While there is an agreed set of procedures to define the LCA goals and scopes, to examine the inputs and outputs of materials, energy, water and land throughout the life cycle and to define the relevant metrics for decision making, the method has also revealed inherent limitations. First of all, the system boundaries are not always easy to define and the assumptions made during the process maybe not consistent, resulting in problems to compare between different results (Keairns et al. 2016; Wolfson 2016). Moreover, in most of the published cases of study, the LCA of a process, product or service is retrospective (measured/estimated data) rather than prospective (forecasted data). Therefore, it does not typically relate to broad steps such as design and development and research or education that can tremendously change the life cycle or even improving it by considering prevention or reduction of manufacturing. This fact is clearly exemplified by the development of Product Category Rules (Laso et al. 2016; Laso et al. 2017). These rules helps and guide about how to assess properly the environmental profile of already existing products leading to Environmental Product Declarations (Environdec 2019). Another particular example of the lack of a broader perspective takes place during the assessment of solid waste treatment and the comparison among landfill, recycling and incineration of waste, which typically do not include an alternative of waste prevention and circular economy. Regarding additional limitations, struggling at quantifying the compromise between the quality of recycled products and its quantity is usually discussed in specialized forums among LCA practitioners (Margallo et al. 2015).

Furthermore, in terms of time and investments it is not always easy and effective or even useful to assess all resources. For example, while the water footprint and cumulative energy demand in the life cycle of a vegetable is relatively easy to calculate, the assessment of provided nutrients to the human body is less straightforward, though it has an obvious health impact. Additionally, as it is usually difficult to present all inputs and outputs and their impact with one measurable index, for example coupling between water footprint and carbon footprint or between energy and material utilization, the decision making is not always straightforward. Indeed, unless a win-win situation could be clearly identified, metrics tend to move in opposite directions thus a trade-off arises. For instance, while the emission of CO_2, NO_x, SO_2 and particulate matter (PM) to the air can be measured, their synergetic effects are very difficult to calculate. This fact holds true as PM creates local pollution problems directly affecting geographically identified areas (local impact) while the release of CO_2 contributes to Global Warming as global impact.

Several approaches are used to try to circumvent the inherent difficulties associated with the full assessment of physical resources and emissions to environmental compartments, leading to a continuous spectrum of types of LCA instead of pure non-intersected LCA types (Suh and Yang 2014). With this continuity in mind, LCA practitioners can differentiate between attributional LCA and consequential LCA, which have applied to different cases of study (Thomassen et al. 2008). According to ISO 14040, which describes the principles and framework for LCA, “two possible different approaches to LCA have developed during the recent years. these are (a) one which assigns elementary flows and potential environmental impacts to a specific product system typically as an account of the history of the product (i.e., attributional LCA), and (b) one which studies the environmental consequences of possible (future) changes between alternative product systems (i.e. consequential LCA)” (ISO 14040 2006). UNEP Shonan LCA database guidance principles defined both approaches as follows:

(a) attributional approach is system modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule, and (b) consequential approach is system modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit (UN, 2011). At last, while attributional LCA provides information about the impacts of the processes used to produce (and consume and dispose of) a product, but does not consider indirect effects arising from changes in the output of a product, consequential LCA provides information about the consequences of changes in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product. Moreover, while attributional LCA generally provides information on the average unit of product and is useful for consumption-based accounting, consequential LCA models the causal relationships originating from the decision to change the output of the product, and therefore seeks to inform policy makers on the broader impacts of policies which are intended to change levels of production. Thus, these two approaches use different methods and systems boundaries and aim to answer different questions, hence they also have different applications.

Attributional LCA is a bottom-up process-based methodology usually product-oriented and mainly devoted to the accounting of resources utilization and environmental burdens. System boundaries are set-up, which define the input and output flows from and to nature and the intermediate flows between existing unit processes. Because of this nature, some kind of cut-off rule must be applied to choose a manageable number of involved unit processes. Usually, most of the published LCA studies consider these attributional features. In attributional LCA or process-based LCA, global, national or regional markets are not considered so the use of natural resources and the environmental burdens are only attributed to the product, process or service identified by the functional unit.

On the other side of the spectrum, other approaches are also available to mitigate the problem of the cut-off rules. A consequential LCA or environmental input-output LCA (Zamagni et al. 2012; Kitzes 2013) is a top-down methodology that accounts for the full set of direct and indirect burdens, as all emissions are considered due to the fact that all of the involved economy sectors are integrated. This methodology provides a way to evaluate the linkages between economic activities and environmental burdens and to overcome the limitations of cut-off problems identified in attributional LCA. This way, consequential LCA, as opposite to attributional LCA, considers market conditions and the potential displacement of products within the economic system. Limitations arise here also, as it is not straightforward the way in which emissions are aggregated by economic sectors or the equilibrium model are applied. As an example, the use of attributional LCA for water footprint of tomatoes account for all direct allocable water usage, from the growth to the cleaning and packaging in the warehouse and at home, consequential LCA would also consider the water displacement due to the tomato being in the market instead of other vegetables. More recently, hybrid approaches have been suggested to overcome the limitations of both types of approaches (Yang 2017).

Current LCA usually struggles also at considering its social pillar, which is also a fundamental component of sustainability. For instance, carbon and water footprints of diverse goods such as cloths or fruits, consider the place that the product is manufactured and the place that it is used, in terms of the difference in the type of water that were used for the product (e.g., green, blue or recycled water) or the emission during transportation from the manufacturer to the distribution center and shops/markets. However, it does consider neither the labor hours nor the social rights of the workers or the health impacts on the consumer in the life cycle (Irabien and Darton 2016).

3. FROM GOODS TO SERVICE

Services play a major role in our daily life. The share of the service sector in economy and in the employees' number growth continuously, which is a distinctive feature of the developed countries. This role of the services was highlighted by Vargo and Lush, as they provided several years ago a new marketing and economic model termed Service Dominant Logic (SDL), which aim to replace the traditional Good Dominant Logic (GDL) (Vargo and Lusch 2004; Vargo and Lusch 2006). According to the SDL, the focus should be displaced from solutions that are based on the production and delivery of tangible values (i.e., goods) to those, which are based on the provision of intangible values (i.e., services). Consequently, this new approach means that from an LCA perspective (environmental approach), the functional unit must be de fined in terms of a service rather than a product, which in turn can be accomplished by a myriad of reference flows as it will have exemplified later on. Moreover, thanks to the SDL, dematerializing of goods is possible, which clearly has a huge potential for environmental improvements both in terms of resource saving and reduction of environmental burdens.

In this sense, services differ from goods due to three key features:

- First characteristic is inseparability, which means that while goods are produced and delivered in two sequential steps, services are produced and deliver simultaneously (i.e., consulting a lawyer).
- Second feature is perishability, thus services cannot be stored or returned (i.e., a lawyer recommendation can be followed or not but once it is given it cannot be returned).
- The third characteristic that differentiates goods from services is the heterogeneity, as the provision of services depends on the place and time of provision and also on the character of the producer and the client and their mutual interactions (i.e., different lawyers may not provide the same counseling).

On the other hand, products can be perfectly heterogeneous no matter the location of the production facility (i.e., tires for cars or pencils for writing). Thereby, services are produced and delivered via joint value co-creation process (Wolfso et al. 2006). Furthermore, this co-creation process shift the provision model from value in-exchange, which resembles the delivery of good from a supplier to a consumer, to value in-use model, which turns the supplier into a provider and the consumer into a customer, and oblige both of them to invest resources and participate in the provision (Vargo and Lusch 2004; Vargo and Lusch 2006). Finally, SDL offers an economic model that is not necessarily associated with the production and distribution of products, but rather with the use and functionality that these products can offer (i.e., servicizing) (White et al. 1999).

Servicizing can also be obtained by merging products and services into a product-service system (PSS) (i.e., the addition of a service to a product to obtain a combination with maximum added value) (Tukker 2004; Gaiardelli et al. 2014). With the increase in popularity of PSS, it has accrued myriad definitions, such as (a) "Marketable systems of products and services capable of fulfilling a user's demand", was proposed by (Goedkoop et al. 1999), (b) "A pure product system is one in which all property rights are transferred from the product provider to the client on the point of sale. A pure service system is one in which all property rights remain with the service provider, and the clients obtain no other right besides consuming the service. A product service system is a mixture of the above. It requires that property rights remain distributed between client and provider, requiring more or less interaction over the life time of the PSS" (Hockerts and Weaver 2002), and (c) "An innovation strategy, shifting the business focus from designing and selling physical products only, to designing and selling a system of products and services which are jointly capable of fulfilling specific client demands" (Manzini and Vezolli 2003).

Concomitant with the growth in interest in PSS due to their greater efficiency and profitability was a more focused consideration of the environmental impact of systems, a natural development owing to the opportunity inherent in the PSS concept to reduce the tangible elements, e.g., materials and energy, of system solutions (Lucas 2018; Wolfson 2016). In this case the terminology was also changed, and PSS was referred to as eco-efficient services (EES), which are systems of products and services that are developed to cause a minimum environmental impact with a maximum added value (Hockerts 1999; Bartolomeo et al. 2003). Another term used is clean services. This is such a service that is competitive with (if not superior to) its conventional tangible or intangible counterparts and one that reduces the use of natural resources and cuts or eliminates emissions and wastes while increasing the responsibilities of both provider and customer (Wolfson et al. 2013, 2014). Such combination of product and service can decrease the environmental impact of the product and many times also the costs of the solution, while increasing the positive social impact, thereby promoting sustainability. In general, there are eight types of PSS that are divided to three groups: i) product-based, ii) service-based, and iii) solution-based (Tukker 2004). Finally, EES are often also termed as sustainable product-service systems, which are designed and marketed to provide customers with a particular result or function without them necessarily having to own or buy physical product in order to get that result (Roy 2002). In addition, the design of these new product-service systems may involve the development or use of products that are more efficient in their use of energy and materials and generate less pollution and waste.

Shifting from GDL to SDL requires a different approach on LCA as it was mentioned earlier. The service to be provided becomes the actual functional unit, thus the products is no longer fulfilling a main role. Nowadays, LCA studies are usually oriented to products (producer perspective) and not to the consumer of that particular good (customer perspective). For instance, the IPCC guidelines for national greenhouse gas emission inventory disregards the emission from imported products and does not consider the role of the consumer in the emission allocation system (Caro et al. 2015). In addition, service's performance is usually measured based on qualities and not quantities success parameters, either by accounting the efficiency of the performance or by assessing what is the customers' satisfaction (Rust and Oliver 1994; Johnston and Jones 2004). Qveys usually perform this uestioners and sur these measures not really account the impacts of the service on the social ,Yet .assessmentor natural environment, as it reflects only the narrow needs, wants and benefits of the customer.

LCA as a tool both in its attributional or consequential approach can be successfully applied to products, processes and services. Eventually, even if the SDL leads to a different approach when using LCA, a certain set of physical resources flows will be required at some point (material or energy). Therefore, servizicing can help at the dematerialization of goods but cannot remove 100% of the materials or energy needs related to the chosen function unit. In addition, as product based S-LCA mainly considers the impacts of the process on workers (e.g.: number of working hours), service based S-LCA also can help at emphasizes the role of the customer in generating and controlling these social impacts (e.g., unfear employment).

Like the LCA of goods, LCA of services or PSSs should include both the inventory of direct and indirect physical resources and non-physical resources, which are the main components of a service (Figure 1). Furthermore, the assessment should consider both the core-value, which is the essence of the value, and the super-value, which accounts for indirect impacts (Wolfson et al. 2010; Wolfson 2016). As such, it should account for all resources and effort that are incorporated into the direct value, co-created by the provider and the customer, (i.e., the core-value,) as well as the indirect delivery of resources and effort throughout the supply-chain, for example the interactions of different suppliers and the provider, to the delivery of 'by-products' to other stakeholders (i.e., super-value). For example, a service of a gasoline station provides gasoline filling as a core-value. Therefore, the resources which are associated with gasoline extraction, production, transport and fill should be assessed together with the resources that are attributed to the pump. Yet the indirect resources utilization in the station itself, from electricity to water, which are part of the super-value, should also be assessed. These burdens can be easily identified with the environmental amortization of burdens from the infrastructure and the additional resources to operate the station, which usually are neglected. Furthermore, besides the direct provider and customer of the core-value, this perspective also accounts for indirect suppliers and stakeholders. Finally, in the case of goods, the supplier is in charge for all resources of the life cycle except the use and end of life stages, even if today producers are more and more responsible also at the end-of-life stage. On the other hand, in service's life cycle, the customer is jointly responsible to the whole life cycle stages, thus also becoming a provider of sustainability to current and next generations (Figure 1) (Wolfson et al. 2010; Wolfson 2016).

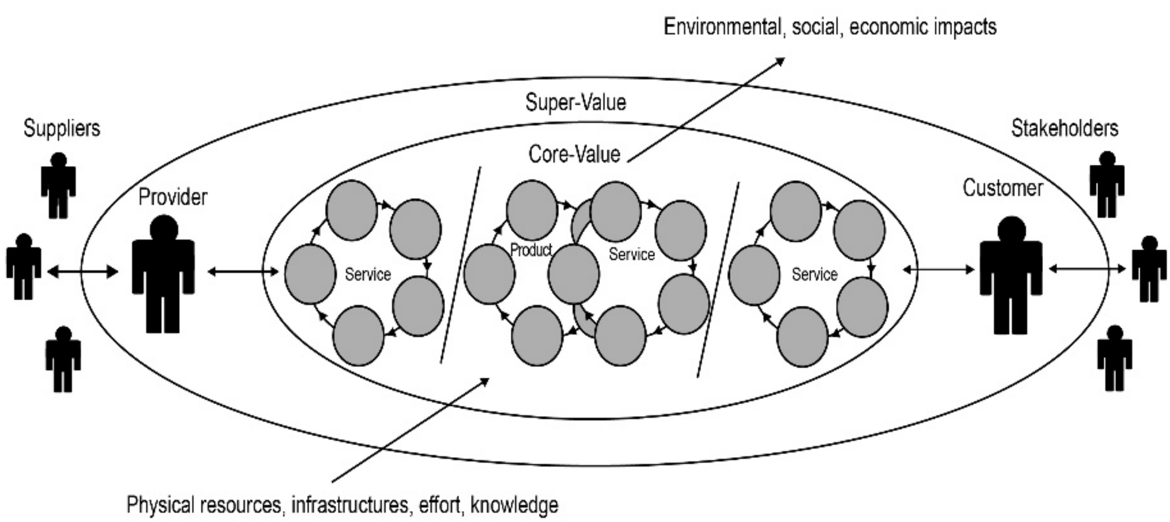

Figure 1. Schematic Illustration of Sustainable Value Co-Creation in the Framework of SDL

At last, moving from GDL to SDL totally changes the perspective and thus the reference or the scenario that should be assessed. For example, instead of food purchase and consume assessing the provision of satiety or pleasure, assessing the provision of body covering and protection instead of assessing the input-output resources of a pair of pants or a fashion item, or offering temperature (i.e., cooling or heating) instead of electricity. In addition, the criteria or the measures of physical resources that are consumed or are emitted during a service are also usually different. Moreover, when intangible values are the targets, their flow and change during the various stages of the life cycle and the value of the whole service for comparison with other alternatives is also changed.

Therefore, the aim of this work is to state the positive impacts in terms of sustainability of moving from a good to a service or a product-service system, changing the focus from the linear purchase-discard of a product to a concerned consumer usage of the product. LCA as a tool can help at servicizing, as the service can become the new functional unit rather than the conventional good used for it. The key role of the client/customer is highlighted. Three cases of study are shown next to exemplify the benefits of the GDL LCA to SDL LCA transition.

4. METHODOLOGY

Moving from GDL to SDL requires different perspective on LCA. Moreover, if sustainability is one of the targets, the LCA should account other aspects then physical resources. Herein, three case studies are introduced, using the following methodology:

1. Definition of the value and the reference scenario, considering both product and service features.
2. Assessing physical resources (e.g., greenhouse gas emission).
3. Assessing nonphysical resources per use or time, and with respect to effort and value hierarchy (i.e., DIKIW pyramid).
4. Interpretation of the effect of servicizing on physical resources.

5. CASES OF STUDY REGARDING THE GDL TO SDL TRANSITION FROM A LCA PRESPECTIVE

To demonstrate the new perspective gained by the use of LCA, three representative examples were selected. The three chosen examples deal with the assessment of physical and non-physical flow resources while bearing in mind the intangible nature of the service. In the first example, the physical resources LCA of clothing is performed, where a scenario that emphasizes the use of a T-shirt is discussed. Then, an example of non-physical assessment with respect to effort and value hierarchy for the service of liquid supply is illustrated considering a plastic bottle as reference. Thirdly, the integration of physical and non-physical resources assessment in the transportation market is used to demonstrate the transition from GDL LCA to SDL LCA.

5.1 Case Study 1: Clothing

This first case study deals with clothing as an essential service. It is more than obvious that clothing provides a dual service, which include both protection from outside weather conditions (e.g.: cold, heat, rain, etc.) and personal projection (e.g.: trademarks, colors, messages, etc.). Conventional GDL will use LCA (for example in its attributional approach) for the discussion of the best environmental performing T-shirt or trouser: plastic fibers, cotton, linen, etc. But, moving from GDL to SDL perspective will discuss the need and the use of the clothing and not just the material used for the clothing.

According to the previous discussion, as the client demands being protected by a certain material to feel comfortable and look proper to others, the functional unit of the service is the need of clothing for a person during a period of time under certain outside weather conditions. With this respect, one important factor related with the client is the use time of a good. Let us use here a T-shirt as a potential reference flow for the aforementioned functional unit. First of all, any T-shirt usually stays most of the time in the cupboard rather than used. (Table 1) Thus, the first question that should be addressed is how to reflect the time that this T-shirt is used in the assessment. This perspective is very important, as most of the goods that we purchase on a daily basis are not used in full capacity. In this particular example, this need of clothing is translated into a T-shirt and its uses. Hence, instead of measuring carbon footprint of an item, carbon footprint per use or per time would be a more accurate environmental metric to present the impact of the item's life cycle on the social and natural environments. In addition, once this T-shirt reference flow has been selected, it should consider that the T-shirt is capable of preventing cold from outside and make the client to look adequately for a certain amount of time, which leads to a different number of usesTable 1. The Carbon Footprint of a T-Shirt, Adapted from (The Carbon Trust 2017)

Life cycle's stage	Core/Super value	Carbon footprint ($g CO_2$-eq.)-50 uses	Carbon footprint ($g CO_2$-eq.)-100 uses
Raw material production	Core value	2.1	2.1
Fiber/textile production	Core value	3.1	3.1
Clothing production	Core value	0.8	0.8
Distribution	Super value	0.3	0.3
Retail	Super value	0.8	0.8
Use	Core value	7.8	15.6
Recycle	Core value	0.4	0.4
Total		**15.3**	**23.1**
Total per-use		**0.31**	**0.23**

The carbon footprint of the various stages of a T-shirt's life cycle assessment is illustrated in Table 1, which corresponds to a classic attributional or product based LCA for different number of uses. As mentioned earlier, even the clothing service will demand physical flow resources as in this case, which is explained by a GDL LCA. The emissions of a 250 g cotton T-shirt over the total life span (assuming global average carbon intensity of cotton production, a useable lifetime of 50 uses and hot water washing after each use) is 15 g CO_2-eq. (The Carbon Trust 2017). As it can be seen, 45% of the greenhouse gases are attributed to the non-use of the shirt (e.g., grow of cotton and production) while 52% are due to the use (e.g., washing, drying and ironing) and the last 3% are attributed to recycling. The first two parts can be reduced by using resources more rationally, from the use of alternative energy during production and to produce domestic electricity to avoiding drying machine that responsible to almost half of the emission of the use stage. Yet, the use time of a shirt is also very important variant, as resources that were consume or pollutants that were emitted during the pre-use stages (e.g., extraction of raw materials, manufacturing and transportation) are embedded emissions and can be utilized more efficiently when the use time increase. Thus, considering the use or wear of a T-shirt as a service and not as a good, requires calculating the emission per use or time. For example, using the T-shirt double the time (i.e., 100 uses), will cut the emission per use of pre-use steps by 50%, while the use stage emission per use will not be changed. Hence, the overall emission per use will be cut by 26%. As such, the emission per-use will be calculated as g CO_2-eq. per use. Moreover, the emission can also be calculated per time, for instance g CO_2-eq. per hour, as one use of a shirt can varied from minutes to hours. Finally, using the same T-shirt twice the time avoids also the emission that are attributed in pre-production, manufacture and delivery of another T-shirt (7.1 g CO_2-eq.), so actually the total emission is only 16 g CO_2-eq. or 0.16 g CO_2-eq. per use, a reduction of around 50%.

Presenting the emission per-use instead of per-shirt, also emphasis the power of the consumer to become a customer and not only be involved in the value co-creation and thus in reducing the emissions, but also be responsible for the environmental impact of the T-shirt use, hence becoming a provider of sustainability. It means that, if according to the good-based assessment, half of the footprint is attributed to the provider due to all pre-use stages (e.g., production and delivery) and the other half to the user, in a service-based assessment the consumer behavior also changes the share of the pre-use emission in the overall emission. Moreover, the customer can also feel his contribution to the reduction of emission per-use, hence change his or her habits, which can motivate him or her to be a smarter user (e.g., buy less shirts or cut the use of dryer and thus further reduce the emission per-use). Finally, the LCA comprise of core-value emissions that directly attributed to the shirt (e.g., production, use and recycle) and indirect super-value emissions (e.g., distribution and retail). However, in the current example the super-value emissions are relatively low compared to the core-value emissions (~7% of the total emissions), and increasing the uses will reduce this relative emission accordingly.

5.2 Case Study 2: Storage of Liquids

Physical flows of resources regarding water, materials, energy and land use of the life cycle of a product, process or service can be usually measured or estimated, and thus properly assessed and compared to others which can perform similarly. On the other hand, non-physical resources like client/customer effort and the level of the value in the DIKIW hierarchy, from data and information to knowledge, intelligent and wisdom (Ackoff 1989), are objectively more difficult to be measured, and the process is even more complex when the various life cycle's stages should be assessed. Yet, shifting the focus from goods to services, oblige also to assess these features and to learn how they can improve the environmental and social impacts.

Let us now consider as case study the need of storing a liquid over a certain period, which is the service that must be fulfilled. Yet, in order to accomplish the service, a product in a form of container or vessel should be used, and even reused for several times, thus this case study is about PSS. Consequently, the reader could establish a clear parallelism with the previous case study, as the physical resources imbued in the life cycle of the container or the vessel that is used to keep the liquid should be recalculated per use or time. Thus the functional unit to be served is the safe storage of a certain volume of a liquid for a certain period of time. The service must assume that there are neither leaks nor contamination and that transportation is possible. For this particular case study, a plastic bottle is a reasonable example of a reference flow, as it can store a liquid during a reasonable period of time with no leaks and easiness of transportation. While from GDL perspective the purpose of the plastic bottle is only to transport the required liquid, from SDL itis additionally defined for refilling purposes of a certain liquid such as water or soda, then plastic bottles production could potentially be reduced if everyone will reuse their own bottles. Moreover, though nowadays using one-time plastic bottles instead of owned glass bottles just make it more comfortable, before the current dominance of the plastic bottles or aluminum cans, in developing countries, liquids were usually transported in owned glass bottles that were suitable for refilling service. In other words, the solution was in front of us all the time and for sure not nothing new.

The clear issue with this reference flow is the environmental degradation. Plastic bottles, which are used on a regular basis all over the world, have very high environmental impact. They are manufactured from petroleum that is used both for polymers' production and also as fuel. In addition, most plastic bottles are not recycled, a process that can reduce their environmental impact (Hopewell et al. 2009). Furthermore, these bottles and other plastics end up in the ocean, reaching marine fauna through ingestion and entanglement (Eriksen et al. 2014). Though recycling service also consumes resources, it can cut the overall carbon footprint of plastic bottle's life cycle by relevant percentages as shown for PET bottles by means of a consequential LCA (Shen et al. 2011). However, bottle recycling requires some effort from the consumer who should become customer and take an active role in waste separation at home and in throwing the bottle to an assigned bin, highlighting the key of the client being a customer.

On contrary to recycling, which uses the bottles as raw material for another product, a processes that consume some resources, reusing the bottle by refilling in the shop (i.e., Zero-Packaging Shopping) does not require extra resources, thereby yields lower environmental impact. This means that a different reference unit is possible: an owned refillable glass/metallic bottle. Immediately, the concept of prevention arises, as the use of additional means (plastic bottles) to serve the purpose is completely avoided. Again, the key element is the possibility to reuse. On the other hand, this kind of service require higher effort from the consumer: he should save the owned bottle, clean it and carry it back to the shop, but also from the provider, which should place a suitable arrangement for this purpose (e.g., storage of the requested liquids). Finally, Zero-Packaging Shopping has also social benefits as it supports local economy, including small and regional farmers and other suppliers, and presents higher transparency along the supply chain (Beitzen-Heineke et al. 2017).

As the main characteristics of a service is the intangibility of the value, the level of this value and its effect on the environmental impact of the whole life cycle should also be assessed. For example, the amount of recycled bottles or the efficiency of bottles recycling service can be increased by moving from a service that include simple alignment of recycling bins, which can be seen as equivalent to data in the DIKIW pyramid, to an alignment that corresponds to the amount and the place of the bins based on needs (e.g., putting bins near supermarkets) and adds also some information about the distribution of the bins in an internet site or an application, thus presenting value that is more in the level of information. Furthermore, accompanying the recycling service with publicity and adverting about the importance of recycling and the uses of the recycled material will increase the value level to knowledge, thus increasing the amount of recycled bottles. Moreover, imbuing education program about recycling, that besides data, information and knowledge also add some way of thinking and acting as well as skills, or addition of policy and taxes or other fees regarding disposal of plastic bottles, might increase the level further to intelligent and even wisdom that can be manifested also by smart shopping and rational use of resources (i.e., reducing).

There are variety of aspects that effect recycling rate, form socio-economic to demographic characteristics (Vining and Ebreo 1990; Sidique et al. 2010b). Yet, there are also different ways to motivate recycling and increase recycling rate. Several researches in the field found that the location of recycling receptacles is a critical factor in affecting the level of recycling receptacle usage (Ludwig et al. 1998; O'Connor et al. 2010) found that by determining the most common point of consumption, the response effort necessary to recycle plastic bottles was potentially decreased, thus the level of recycling was increased. Furthermore, Austin et al studied the effect of sign prompts on the recycling behavior of faculty, staff, and graduate students in two academic departments of a large university (Austin et al. 1993). They found that the sign prompts increased recycling behavior, whereas installation of the sign prompts in close proximity to receptacles in one department resulted in a 54% improvement over baseline. The posting of sign prompts over containers 4 m apart from another department resulted in a 17% improvement. Positioning the signs and receptacles in the close proximity resulted in a 29% improvement over baseline. In another research, Vining and Ebreo found that after a 3-year recycling education program residents' knowledge of recycling issues was more accurate, their motivation reflected greater concern for the environment, and their recycling behavior increased (Vining and Ebreo 2008). Additionally, Sidique et al analyzed the effects of various recycling and waste management policy variables on recycling rate and found that variable pricing of waste disposal increases the rate of recycling (Sidique et al. 2010a). Consequently, the transformation of the client into a customer together with the provider seems to play a major role. A larger non-physical flow is requested to the client (a customer as a matter of fact) and the provider at the different levels of the DIKIW pyramid in order to provide the service defined as storage of a liquid over a certain period. The trade-off that shows up is clear: a greater effort from the customer, carrying its owned bottle, and the provider, using a non-conventional configuration of shelves, etc. in the shop or supermarket (i.e., non-physical flows) would lead to a better environmental profile (i.e., reducing the amount of plastic for a single-use bottle).

5.3 Case Study 3: Movement of Persons

Transportation, which can be simply seen as movement from one point to another, is used for many purposes: to commute to work or study, to transfer or delivery of merchandise or to many other daily activities (e.g., shop, entertainment, etc.). In this case study, the service to be provided is the movement of one person from one location to another, under safety conditions and reasonable period of time and price. Once more, the reader could detect a parallelism with the other two previous case studies, as the resources should be assets not just per person or kilometer but also per time. The functional unit to be served is the safe movement of a person from one geographical point to other geographical point within a human reasonable period of time. For this particular case study, transportation by car in terms of passenger and kilometer traveled (PKT) becomes an understandable example of a reference flow, as it can serve well to the mentioned purpose.

Undoubtedly, the transportation sector (not only cars) has a huge impact on the environment, especially from the combustion of fuels that releases air pollutants and greenhouse gases (Berntsen and Fuglestvedt 2008), but also in a lesser way from the dominance of infrastructure, such as asphalt roads (Butt et al. 2014), railways, maritime ports or airports. In general, there are several transportation solutions, from private vehicle, either car or motorcycle (i.e. goods), to public transportation solutions like bus, metro, train (i.e., product-based PSSs). But recently, due to the high cost of transportation means and their operation and maintenance and due to environmental concerns, more service- or solution-based PSSs are offered in the transportation market, from carpooling (i.e., a service where some passengers share a journey) to car sharing (i.e., a service where various users share the same car). At last, using a videoconference meeting service instead of driving to a meeting point or secure electronic payment platforms instead of driving to the bank (i.e., pure service) can serve as reference flows of a different functional unit (as the functional unit regards to the movement of a person and not to the purpose).

When moving from goods perspective to services perspective, the main value of the process should be changed from a car or other transportation means to a journey. As an average time usage of private car is around 5% of the year (Vivier 2006; Kenworthy and Laube 2016), the effect of product's use intensity on greenhouse gases emission is very important. The use of a car for more journeys (i.e., for more kilometers and longer time), increases the emission of greenhouse gases from operational components (i.e., core-value like running, maintenance and fuel production), but does not change the non-operational stages (i.e., super-value such as vehicle manufacturing, insurance and infrastructures, which their emissions are not directly assigned to the journey) as shown in Table 2, which is sourced

Table 2. Environmental Assessment of Passenger Transportation of Conventional Gasoline Sedan (PKT-passenger kilometer traveled), Adapted from (Chester and Horvath 2009)

<table>
<tr><th>LCA component</th><th>Carbon footprint (g $CO_{2\text{-eq.}}$ /PKT) (11,000 mile per year)</th><th>Carbon footprint (g $CO_{2\text{-eq.}}$ /PKT) (22,000 mile per year)</th><th>Carbon footprint (g $CO_{2\text{-eq.}}$ /P*h)</th></tr>
<tr><td>Vehicle active operation:
running, cold start</td><td>144</td><td>144</td><td>1,4400</td></tr>
<tr><td>Maintenance:
vehicle maintenance, tire replacement</td><td>10</td><td>10</td><td>1000</td></tr>
<tr><td>Fuel production:
refining and distribution (includes through fuel truck delivery stopping at fuel station).</td><td>25</td><td>25</td><td>2,500</td></tr>
<tr><td>Vehicle inactive operation: idling</td><td rowspan="7">61</td><td rowspan="7">30</td><td rowspan="7">6,100</td></tr>
<tr><td>Manufacturing:
vehicle manufacturing, engine manufacturing</td></tr>
<tr><td>Insurance:
vehicle liability</td></tr>
<tr><td>Infrastructure construction:
roadway construction</td></tr>
<tr><td>Infrastructure operation:
roadway lighting, herbicide spraying, roadway salting</td></tr>
<tr><td>Infrastructure maintenance:
roadway maintenance</td></tr>
<tr><td>Parking:
roadside, surface lot, and parking garage parking</td></tr>
<tr><td>Total</td><td>240</td><td>210</td><td>24,000</td></tr>
</table>

from a classical attributional LCA (Chester and Horvath 2009). Thus, doubling the use of a car from 11,000 mile·yr^{-1} to 22,000 mile·yr^{-1} (17,700 km ·yr^{-1} to 35,400 km ·yr^{-1}) will result in the reduction of 12.5% of the emission PKT, this is from 240 g CO_2-eq PKT to 210 g CO_2-eq PKT (Chester and Horvath 2009). Moreover, if a journey from one point to another is the service to be assessed, then the time that a certain journey takes, due to traffic, road maintenance or accidents, should also be considered. In this case, though the kilometer and number of passengers are the same, the amount of gasoline that is used in different journey time is different and it might be that the component of the vehicle maintenance will also alter. Thus, from a service perspective, we should present the greenhouse gases emission per time in order to compare between different scenarios and choose the best alternative. For example, assuming the average velocity of the car is 65 mile·h^{-1} (approximately 100 km·h-1), then the total emission per hour is 24,000 g CO_2-eq. per passenger. Hence, a traffic jam that doubles the traveling time, will increase the operation emission by 70%, as the gasoline usage is not doubled due to lower speed and a lot of stops. On the other hand, the non-operational components are almost unchanged. Thus, a travel of 2 h instead of 1 h for the same distance will emit 36,530 g CO_2-eq. per passenger or 52% higher emission per kilometer.

The effect of the value's level in the DIKIW hierarchy (Ackoff 1989) on the environmental impact can also be illustrated in the transportation field (Table 3). Changing from private car journey that is based solely on product to the use of PSSs or even pure service, requires higher co-creation and more effort from the customer, but also increases the level of the value in the DIKIW hierarchy. If using a car alone (i.e. pure good) is equivalent to a level of data, addition of transport navigation apps like Waze or Google Maps (i.e., product-based PSS) that add information about the best way to perform the journey, increases the value level to information, and saves time, gasoline and emission and also costs (Table 3). Additionally, car sharing that requires higher level of co-creation (service-based PSS) and splits the resources, physical and non-physical, between the provider and the customer differently, thereby yielding knowledge, also reduces the environmental impact. In the same manner, public transportation that offer solution-based PSSs further increases the co-creation and reduces the emission per kilometer per person traveled yielding more intelligent solution. Moreover, these PSSs not only increase the use intensity or the time that the product is utilized, but also allow to be used with more passengers, thus having lower emission per capita. In addition, both PSSs also add important social impact like equity, affordability and accessibility, while public transport also reduced costs and it is usually more time affective and less sensitive to traffic changes as it uses assigned lines. At last, using various services such as paying or ordering applications or pay-per-view services, generate wise solution that make unnecessary the need to perform the journey at all, hence change the value from a journey to paying or ordering and totally avoid emissions. This way, the service of movement will be avoided at all, then the corresponding physical flows of any of the chosen reference flow, as no movement of person is envisaged. In the previous case studies, this option seems to be impossible as the need of clothing or storing liquids cannot be avoided.

Table 3. Carbon Footprint for Various Transportation Solutions (PKT-passenger Kilometer traveled), Adapted from (Chester and Horvath 2009)

Solution	**PSS type**	**DIKIW**	**Carbon footprint (g CO_2-eq./PKT)**
Car	Pure product	Data	234
Car with google map*	PSS, product-based	Information	210
Car sharing**	PSS, service-based	Knowledge	185
Public transportation***	PSS, solution-based	Intelligent	107
Paying by internet instead of driving to the bank or working from home	Pure service (no movement of person)	Wisdom	0

*10% reduction of gasoline
**10 times uses of the car compare to private car
***light rail.

6. CONCLUSIONS

Sustainability as a service does oblige each provider and consumer to co-create sustainable values and also to provide sustainability to current and future generations. Moving from GDL to SDL will change the focus from what we want to what we really need. It also requires looking differently at the LCA tool, considering different boundaries and reference scenarios as well as non-physical resources like effort and the level of the value.

In general, every need can be fulfilled by a service, which defines the functional unit under the approach of LCA. In addition, moving from a good to a service or a product-service system, changes the focus from a product to the dematerialized alternatives of that product. It also requires higher investments of resources from the client, which thus turns into a customer and co-creates the value together with the provider, thereby allows to reduce the environmental impacts. In addition, servicizing increases the level of the life cycle's value within the DIKIW hierarchy, where eventually the customer could be also turned to a provider and reduce further the environmental impacts. Finally, the environmental, social and economic assessment's quantitative impacts of the LCA are expected to be different when the need is changed from a good to service, as explained in the different case studies.

When service is the focus, physical based LCA should be recalculated based on nonphysical resources. For instance, considering the use or wear of a T-shirt as a service and not as a good, requires calculating the carbon footprint per use or time instead of emission per item. Thus, as 50% of the emission of the various stages of a T-shirt is assigned to the pre-use stages (e.g., extraction of raw materials, manufacturing and transportation) and the rest is due to use stages (e.g., washing, drying and ironing), increasing the uses and measuring the emission per use instead of emission per item, will reflect more accurately the effect of the life cycle on the environment, and will allow to manage the life cycle more efficiently.

Changing the LCA perspective from GDL to SDL also requires to add to the assessment nonphysical resources like time and effort. As the main characteristics of a service is the intangibility of the value, the level of this value and its effect on the environmental impact of the whole life cycle should also be assessed. For example, the amount of recycled bottles or the efficiency of bottles recycling service can be increased by moving from a service that include simple alignment of recycling bins, to an alignment that corresponds to the amount and the place of the bins based on needs, and adds also some information about the distribution of the bins in an internet site or an application. Moreover, accompanying the recycling service with publicity and adverting and imbuing education program about recycling or addition of policy and taxes or other fees regarding disposal of plastic bottles, will also increase the level of the nonphysical value, and as a result reduce the effect of the physical life cycle on the environment.

Finally, smart servicizing of the product, like in the case of using google map application when driving a private car or using car sharing service, will not only increase the level of the value but also decrease the carbon footprint per passenger per kilometer. Furthermore, increasing the level of co-creation, for example using public transportation (i.e., PSS) instead of private car, can cut the emission by more than half. Yet, using pure service like online purchase instead of using a car to go to the bank or the cinema, might tremendously reduce the emissions.

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