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A new method for Product Service System: the case of urban waste management

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Abstract

The growing attention on environmental and social sustainability issues is pushing companies to move towards new business models. In this context, PSS (Product Service System) seems to be one of the most suitable model to foster the transition to sustainable economic models. The PSS is composed of a mix of tangible products and intangible services. The method proposed in this paper supports the PSS design. The objective of this work is to integrate careful assessment of economic, environmental and social sustainability supporting the transition towards new business models and strategic company decision-making. The method is then validated through a case study on the management of urban waste.

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Keywords: Product-Service System; PSS method; Environmental Sustainability; Social Sustainability

1. Introduction

Nowadays, the international production context pushes companies to continuous innovation, encouraging the identification of new business opportunities. In this context, along the last twenty years, many companies associated services to their physical products in order to create benefit for customers. This kind of product is called Product Service System (PSS) [1]. PSS "consists of a mix of tangible products and intangible services designed and combined, so that they jointly are capable of fulfilling final customer needs" [2]. PSS designing represents a new challenge for manufacturing companies. They must be able to design no more single products, but a set of integrated and complex systems, and they should be able to sell not products ownership but their use.

However, PSS' design is really different than single products' design. Thus, it is necessary to guide designers in this transition phase. A recent and very interesting literature review shows that a careful PSS' design, with attention on sustainability's issues, is fundamental to guarantee environmental, as well as economic improvements. [3]. In general, sustainability is composed of three pillars: economic, environmental and social ones. While the first topic has already been addressed in correlation with PSS, the environmental and social aspects have often been neglected or just mentioned [4]. Methods present in the literature for PSS' design focus in fact specifically on the integration of products with services. Usually, grate attention is given to user needs and market analysis and construction of the business models. The challenge of this paper is therefore to shift the attention towards PSS designing phase and to introduce a method that support designers in the inclusion of economic, environmental and social assessments. In particular, research questions addressed in this paper are: How is it possible to support designers in PSS' design? What are methods/tools that allow to integrate all the three pillars of sustainability (i.e. economic, environmental and social)?

The paper is organized as follows. Section 2 describes the state of the art related to PSS and its correlation with environmental and social sustainability aspects. Section 3 introduces and describes the new framework proposed. Section 4 illustrates the application of the proposed method to a case study related to the management of municipal waste. Finally, the Conclusion closes the last part, Section 5.

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2. State of the art

The concept of PSS appears for the first time in a research publication at the end of ’90 years, in the Journal of Cleaner Production. The authors proposed a report about sustainability, where they defined PSS as “a marketable set of products and services capable of jointly fulfilling a user's needs” [5].

Since then, the literature concerning PSS proved that this concept is becoming a new emerging trend for manufacturing companies, where the main focus is to sell no more just a product but rather its usage and performances. This phenomenon concerns the evolution from a traditional product-centered business model to a new service-oriented one. According to this trend, several authors have conceptualized the shift from products to PSS through various concepts: “servitization” [6], “transition from products to services” [7], “going downstream in the value chain” [8], “product-service systems” [9], “moving towards high-value solutions, integrated solutions and system integration” [10] [11], “manufacturing/service integration” [12], “sub-area of functional sales” [13, 14]. All these authors converge into the concept of solutions defined as innovative combinations of products and services leading to high-value and unique responses to customers’ needs.

As already mentioned in the present Introduction, the modern sustainability thinking considers three main dimensions: economic, environment, and social wellbeing [15]. From the economic viewpoint, services create new market potentials and high profit margins, and can contribute to high productivity by means of reduced investment costs along the lifetime as well as reduced operating costs for the final users [16].

In literature, there is evidence that service-enhanced products can provide not only a higher customer satisfaction [17], but also a great advantage on environmental sustainability [18], especially when combining PSS with remanufacturing [3, 19]. In particular, sustainability is assuming a relevant role in both customer choices as the people attention to energy saving and environmental issues are increasing on the markets [20]. From the environment viewpoint, PSS provides a more conscious product usage thanks to the service functionalities delivered, increasing resource productivity and a close loop-chain manufacturing [19]. In fact, PSS is a promising business approach that has the potential to increase environmental sustainability performance, when compared to traditional products and services. The implementation of best practices for ecodesign and for PSS development has the potential to increase the environmental performance of the developed PSS, supporting the transition towards a more environmentally sustainable system and society [21].

Different authors have developed methodologies to design a PSS. In particular, the following ones mentioned here are those proposed specifically in the PSS domain: Service CAD, Service Model and Service Explorer, Integrated product and service design processes, Fast-track Total Care design process, PSS Design, Heterogeneous IPS2 concept modelling [22].

For these methodologies there is a clear link between the PSS notion, dematerialization and sustainability and their works trace the major ideas making PSS fundamentally sustainable. The three basic principles of sustainable development: economic, social and environmental, are treated to different extents. Recommended models and tools cover more general environmental tools such as Life-Cycle Analysis, Design-for-X, whilst some specific PSS and service tools cover environmental aspects [23].

Still, this challenge remains: PSS must integrate economic, environmental and social considerations in a holistic approach in order to produce radical changes and identify the degrees of freedom for change in the overall production and consumption system. The method proposed in the present paper tries to overcome this difficulty, offering the holistic approach to PSS sustainability, especially bringing into the discussion the social dimension of sustainability, till now less addressed in literature, compared to the others.

3. Method

The method proposed in this paper supports the PSS design. This approach is targeted to enterprise’s designers as supporting tool for transition towards new business models and strategic company decision-making. Through the literature review, emerged a real difficulty in a transversal method generalization for all the PSSs. This work was developed to answer to these critical issues.

Nine steps, guiding designers in a systematic process, compose the method. Sustainability guides all steps of the following method both qualitatively and quantitatively. The structure of the proposed PSS method (steps and relative methods/tools), presented in Figure 1, wants to investigate phases poorly covered by the existing Service Engineering methodologies as Lindal explains in his paper [24]. The flow starts from a deep analysis of user needs (Step 1) to understand behaviours, attitudes, ideas, criticality from different perspectives and, consequently, define a goal. Indeed, the starting point to launch a new product is the customers’ potential request.

An "AS-IS" analysis of reference sector is then carried out (Step 2). Through an in-depth analysis of the local context, companies identify internal and external factors in terms of strengths, weaknesses, opportunities and threats that are important to achieve the goal. Thus, a qualitative analysis takes place and significant parameters are identified. Context analysis is fundamental for a correct declination of organization strategic objectives in operational objectives.

Set out below is goal setting (Step 3). It allows translating previous outputs in specific, measurable, assignable, realistic, and time-related objectives (e.g. S.M.A.R.T. method [25]).

At this point, possible constraints are identified (Step 4). It means to understand and take into account the political, economic, socio-cultural and technological environment that an organization operates in.

A PSS’s Concept, which satisfies goals and respects constraints, will be defined through Business Modeling (Step 5). That allows to create a model that is a simplified view of PSS. This model allows designer to focus on one or more PSS’s important aspects. There are many Business Modeling techniques such as: Data-Flow Diagram, UML or IDEF-3.

Models are interchangeable. Designers can choose the most functional model to their specific PSS [26].

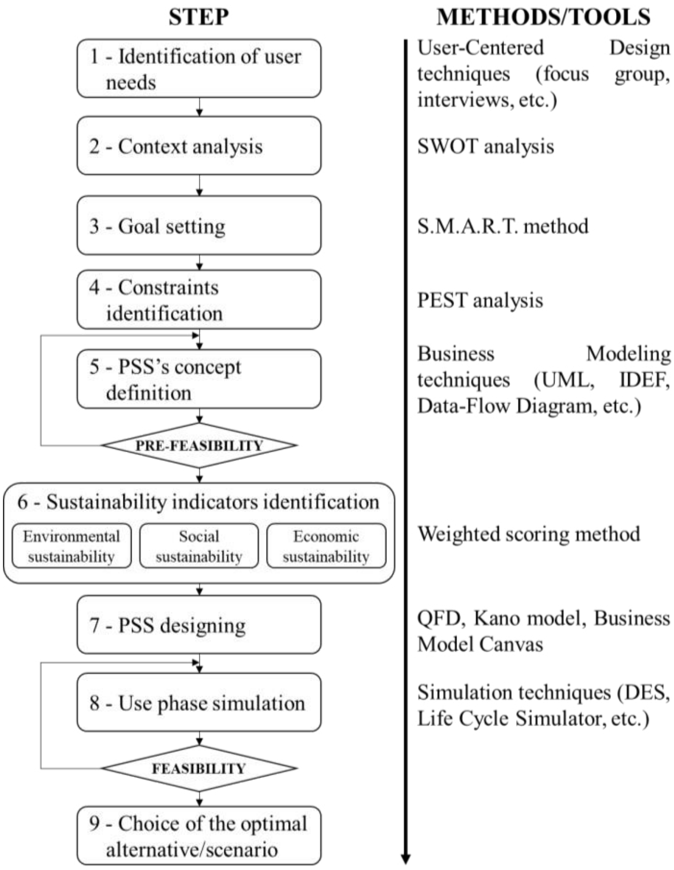

Fig. 1. PSS Designing Method

At this stage, data cross-checking must be done. The test shall be carried out among objectives, identified constraints and PSS's characteristics. If cross-check is not compatible, it is necessary go back to Step 5 and to redefine PSS's concept (it is repeated same loops until there is a perfect cross-breeding), otherwise designers can proceed with the flow. Process pre-feasibility can be evaluated through this check. At this point, designer has an idea of PSS and he/she is able to quantify PSS's most relevant sustainability aspects (Step 6), selecting and prioritizing the relative indicators and targets to be achieved. Firstly, the method presents classification of three sustainability fundamental pillars: environmental, social and economic sustainability. Each sustainability aspect has three different detail levels to which correspond related indicators, methods and tools. Levels choosing depends on the importance of each aspect. Designer can decide the level to adopt in accordance with goal setting and information about sustainability dimensions.

At this stage designer maps user needs with PSS functionalities in order to elicit final requirements (Step 7). He/she creates a highly competitive business model that is directly related to technical PSS's characteristics. When the technical choices are edited, the business model changes automatically. Detailed design must be laid out in functional way that can be modified easily, according to the simulation phase results.

Designer defines different scenarios and identifies fixed and variable parameters to simulate the use phase (Step 8). Dedicated tools can be used for this aim. According to the simulation results, designer checks which scenario best fits the selected indicators and, if necessary, come back to PSS Designing phase and modifies variable parameters (it is repeated same loops until selected indicator values are obtained). Thus, designer can use tools to simulate hypothetical use scenarios that might be encountered. The same tool shows the incidence of the design choice on PSS's life cycle. Designer is, therefore, able to understand what are the amendable levers to improve PSS sustainability. The designer has to take into account established objectives and identified constraints. At the end of method, he/she chooses optimal scenario after the evaluation of carried simulations (Step 9).

4. Case study

In order to validate the proposed method, it has been implemented in collaboration with three Italian actors: a local administration, a public–private company that deals with the collection, transport and treatment of waste and a small enterprise, which produces waste recycling areas.

The main need refers to the management of municipal waste, which is one of the most awkward problems that local administrations must face. Investigating the current scenario through a SWOT analysis, it emerges that the collection phase is increasingly important compared to the disposal phase. On one side, the central collection negatively affects the quality of the collection. On the other side, the Door-to-Door (DtD) collection increases the job-related injuries and makes the resources management more difficult. Any system inefficiencies have repercussions in the hygienic-environmental and social aspects as well as the economic one.

According to the previous highlights, the following goals have been set:

- Increase the quantitative and qualitative level of waste separate collection in order to ensure a high degree of materials recycle and reuse, valorize organic waste and reduce the related environmental impact;
- Optimize the resources management and reduce costs;
- Sensitize citizens and incentivize their participation;
- Improve overall security and reduce acts of vandalism.

Their achievement must be compatible with regulatory, territorial and economic constraints. Legislative Decree 152/2006 establishes the target of 65% as minimum percentage for municipal waste separate collection. The collection area should be easily accessible by all citizens in both rural and urban areas. The cost of any possible solution must not exceed the current one. Such requirements allows defining the PSS concept with consists of recycling area equipped with several systems aimed at: (i) user identification to reward the virtuous behavior of the citizen; (ii) waste characterization to support users in the correct waste disposal and simplify the inspection; (iii) providing a wizard procedure to improve the system usability; (iv) ensuring the traceability to optimize the waste collection schedule and routes; (v) guaranteeing the operators and citizens security. It includes all key elements of PSS such as the cohesive delivery of products (recycling area) and services (i.e. waste management and traceability, security, etc.), the pay-for-use model and the creation of a network of actors (local administration, public–private companies and citizens).

In the pre-feasibility phase it has been preliminary verified the capability of the PSS to satisfy the stated goals and respect all constraints, exploiting the Quality Function Deployment tool. To evaluate the efficiency, efficacy and sustainability of the proposed PSS, several indicators has been defined:

- Per capita waste production less than 500 kg and 75% of municipal waste separate collection;
- Injury reduction;
- 10% Waste management and maintenance cost reduction;
- Environmental impact reduction.

At this point, a detailed design of PSS has been realized. It consists of four main modules: central unit, smart bins and informative panels, and SW. The first one includes a monitor, a RFID reader, a scale, a labels printer, and three cameras. The second ones consists of at least six bins of different size and colors, according to the waste type, equipped with a smart opening system and fill level sensors. The third ones is easily understandable and support citizens in the waste disposal. The last one allows the data analysis and the resources management.

Goals, constraints and PSS features have been logically connected to effectively support the simulation, feasibility verification and redesign activities (Figure 2). Ten scenarios has been hypnotized and simulated, varying the following parameters: bins numericity and location of recycling areas, waste collection management (i.e., garbage trucks and routes), and subscription. The simulation allows to identify the best solution, which consists in 20 recycling areas able to satisfy citizens' needs, installation of 6 bins in each recycling area, definition of 3 picking for each week, use of 15 trucks (3,500 kg payload truck diesel fuel). To validate the robustness of the method and to verify the advantages obtainable by the identified best solution, real data have been derived to quantify the benefits obtainable in economic, environmental and social terms. The aim was to compare the new waste collection management service system, called in the following Waste Management Service (WMS), with the previous Doot to Door system (DtD). The Fabriano city, located in the center of Italy, has been selected as test case. In this city, the WMS system has been implemented in substitution to a DtD system from 2016 and data related to the two systems have been acquired in collaboration with the local administration. In particular, data related to the DtD system are related to year 2015, while data related to WMS are related to 2016. Three analyses have been conducted: economic evaluation, environmental analysis (Life Cycle Assessment – LCA) and social evaluation. Assumptions and results are shown in the following paragraphs.

Economic evaluation. Economic data related to the two systems (WMS and DtD) allow to derive some important cost voices. At first, local administration registers an increasing of revenue coming from the production of a high quantity of recyclable wastes. Passing in fact from 60% to 80% of recyclable wastes, companies in charge to recycle materials recognize major economic benefits to the local administration. The related reduction of wastes direct to the landfill is about 8%.

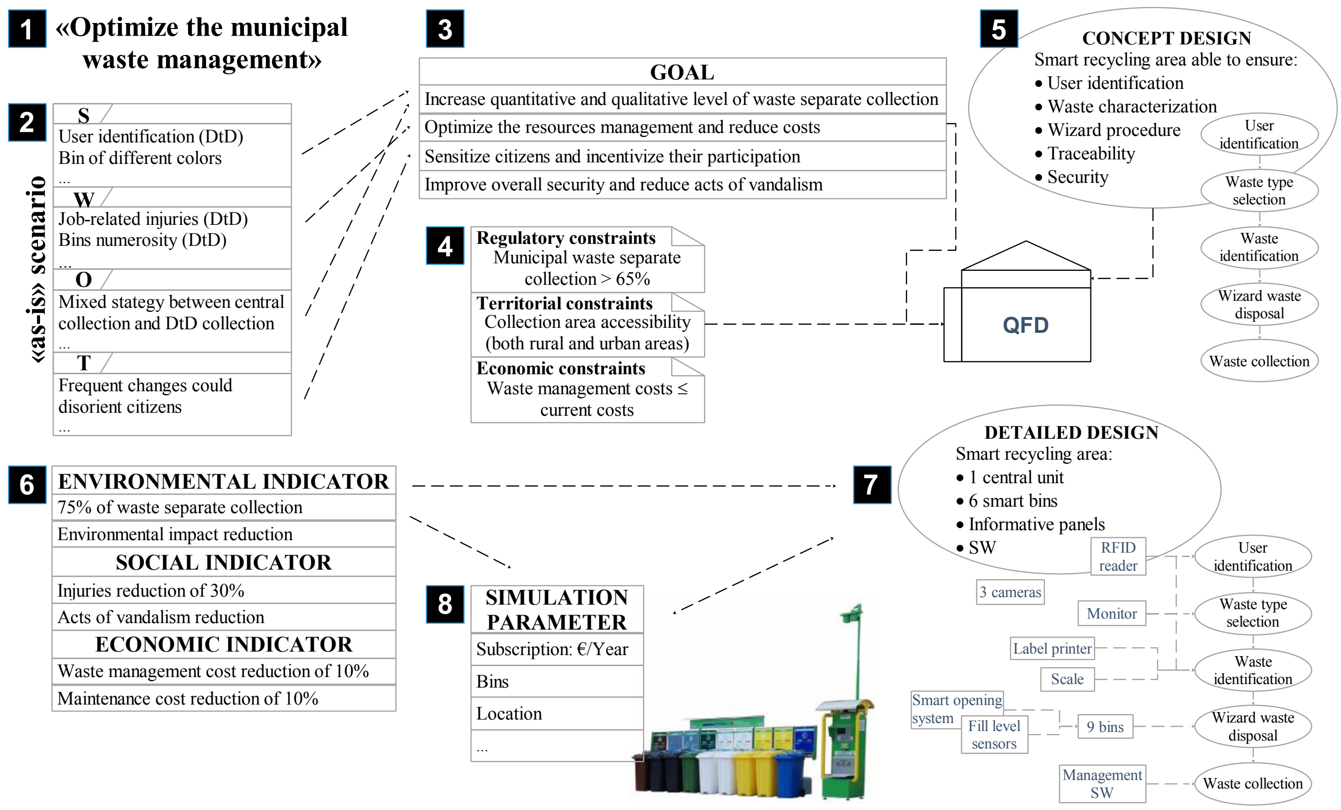

Fig. 2. Extract of the method application and its logical connections

Furthermore, the new WMS allows the reduction of transport costs (about 25%), in particular in the number of trucks involved in the waste management, which pass from 15 to 10 vehicles, and a consequently reduction of maintenance, number of operators and their related costs. The reduction of path (due to the presence of a minor number of picking waste points in WMS in respect to DtD system) also contribute to an economic saving. To all these elements, the reduction of injuries for operators (which will be discussed also in the social evaluation) determines a significant reduction of waste management related costs.

Environmental analysis. The objective is to compare environmental performances of the new WMS system and the previous DtD one, in order to validate its choice. The method and tool applied to realize this comparison was the LCA and the study was performed in accordance with the international standard ISO 14040/14044 [27, 28].

The functional unit was defined as "the management of urban waste for a district of the Fabriano city for 1 year". Two different management systems have been evaluated, i.e. the WMS and the DtD. The district considered in the analysis presents 5 recycling areas, each one equipped with 6 smart bins.

The system boundaries are defined considering the current social and cultural conditions in Italy. Table 1 contains the life cycle phases and the related main items included in the analysis. Observing life cycle inventory data, it is possible to notice that the WMS system presents a higher number of component, due to the presence of smart elements (e.g., central unit, electronic components, video camera, etc.), if compared with those ones of the DtD system. But on the other hand, the WMS allows guarantying a better quality of the waste collected.

Table 1. Life cycle phases and related main items included in LCA analysis

Life Cycle Phase	DtD system	WMS system
Material and Manufacturing	Materials of the traditional bins Manufacturing processes of traditional bins Capacity of bins Life time of bins	Materials of smart bins Materials of informative panel Material of central unit Electronic components of the central unit Electric components of the central unit Video camera components Capacity of bins Life time of bins; Life time of electric and electronic components
Use phase	Path (km) Picking number per week Truck typology Fuel typology	Path (km) Picking number per week Truck typology Fuel typology Electric consumptions
EoL	Waste typology Waste recycling rate for each waste typology Waste recycling processes Quality of waste	Waste typology Waste recycling rate for each waste typology Waste recycling processes Quality of waste

In fact, the user identification and the waste characterization at the moment of the waste disposal, determine a high level of attention for the citizen and as a consequence a minor pollution degree in the waste, thus, increasing its recycling rate. Passing from DtD system to WMS, the quality of the recycled wastes (i.e., the percentage of recyclable wastes) increases from about 60% to 80%. The life cycle inventory has been supported by the Ecoinvent v.3.2 commercial database and therefore background data have been used to model the two waste management systems considered. The software Gabi has supported the life cycle impact assessment phase.

The environmental impacts have been calculated according to the ReCiPe mid-point - Hierarchist (H) version - Europe (Goedkoop et al. 2009, Huijbregts et al. 2017) life cycle impact assessment (LCIA) methods. For space reasons, results are shown for the Climate Change impact category (expressed in kg of CO2 equivalent) in the following Figure 4.

The interpretation of the LCA results allows to derive the following considerations. The WMS system presents better environmental performances in comparison with the DtD ones, if the entire life cycle is observed. This is mainly due to the higher quality of wastes, which is reached with the implementation of the WMS system. If only the manufacturing phase is observed, the WMS burdens on the environment more than the DtD, due to the presence in the WMS system of additional electric and electronic components. However, the possibility to recycle a high percentage of waste, determines a very significant advantage for the environment, thus making the WMS preferable, under environmental aspects and for the entire lifecycle, to the DtD system.

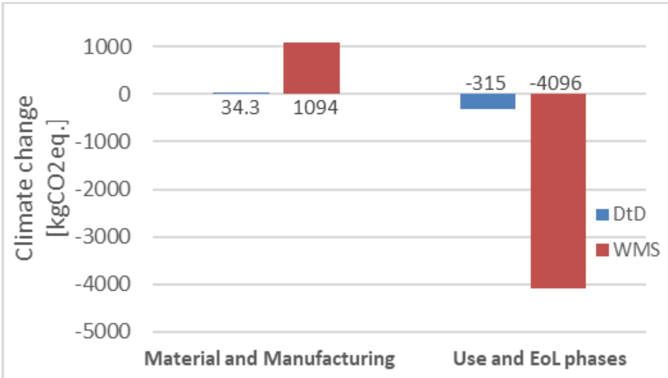

Fig. 4. Environmental impact of DtD and WMS systems

Social evaluation. The implementation of the WMS system in the city of Fabriano started in year 2016, allowing the municipal administrators to observe a sensible decreasing (about 40%) of work-related injuries for operators involved in waste management operations. The DtD waste management system had registered in fact a high number of injuries for operators (e.g., pains in the neck, shoulders and arms), due to continuous and very numerous manual waste picking operations and consequently getting-in and out from trucks.

Picking automations in trucks and the presence of a minor number of recycling areas determine, for the WMS system, better working conditions for operators. To this benefit, also a reduction of act of vandalism in the city has been registered, due to a capillary control of the territory with cameras installed in each recycling areas.

Observing the extensive literature related to waste management systems, numerous are the case where LCA is used [29, 30], confirming it appears as a valid instrument to evaluate their environmental performances [31]. Few examples in this field propose instead the consideration of economic aspects, e.g. [32,33] present the combination of LCA and Life Cycle Costing (LCC) analysis, while social considerations are usually ignored. This trend confirms the validity of the tools used in the present analysis (LCA, business and economic tools) and the novelty, in a PSS design, of their mutual integration, also with social considerations.

5. Conclusions

The present paper presents an innovative method to support the PSS design. Addressing the recent limits of PSSs, the new method proposed includes social and environmental considerations, in addition to economic ones. Nine steps, guiding designers in a systematic process, compose the method, which has been verified through its application on a real case study: the management of urban waste. The case study shows how the implementation of the method has supported the designing of a PSS able to reduce not only costs, but also social and environmental impacts. Future works will consist in the application of the method to different contexts and in the evaluation of its impact (in terms of time and knowledge resources) that it implies in comparison with traditional PSS's design processes.

References

[1] Manzini E., Vezzoli C.; A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize. Journal of Cleaner Production; 2003, Volume 11, Issue 8, Pages 851-857.
[2] Tukker A., Tischner U.; Product-services as a research field: past, present and future. Journal of Cleaner Production; 2006, 14:1552-1556.
[3] Lindahl, M., Sundin, E. & Sakao, T., 2014, Environmental and Economic Benefits of Integrated Product Service Offerings Quantified with Real Business Cases, Journal of Cleaner Production, vol. 64, p. 288-296.
[4] Morelli N. Product-service systems, a perspective shift for designers: a case study: the design of a telecentre. Design Studies; 2003, 24:73-99.
[5] Goedkoop M.J., Van Halen C.J.G., Te Riele H.R.M., Rommens P.J.M.; Product Service systems, Ecological and Economic Basics. Journal of Cleaner Production; 1999.
[6] Baines T.S., Lightfoot O., Benedettini O.; The servitization of manufacturing: A review of literature and reflection on future challenges. Journal of Manufacturing Technology Management; 2009. Vol.20, no.5, pp.547-567.
[7] Oliva R., Kallenberg R.; Managing the transition from products to services. International Journal of Service Industry Management; 2003. Vol.14, no.2, pp.160-172.
[8] Wise R., Baumgartner P.; Go downstream: The new profit imperative in manufacturing. Harvard Business Review; 1999. Vol.77, no.5, pp.133-141.
[9] Tukker A.; Eight types of product-service system: eight ways to sustainability? Experiences from SusProNet. Business Strategy and the Environment; 2004. Vol.13, no.4, pp.246-260.
[10] Davies A.; Moving base into high-value integrated solutions. A value stream approach. Industrial and Corporate Change; 2004. Vol.13, no.5, pp.727-756.
[11] Windahl C. and Lakemond N.; Integrated solutions from a service-centred perspective: Applicability and limitations in the capital goods industry. Industrial Marketing Management; 2010. Vol.39, no.8, pp.1278-1290.
[12] Schmenner R.W.; Manufacturing, service and their integration: some history and theory. International Journal of Operations and Production Management; 2009. Vol.29, no.5, pp.431-443.
[13] Lindahl, M. and Ölundh G., 2001, The Meaning of Functional Sales. Life Cycle Engineering: Challenges and Opportunities, 8th International Seminar on Life Cycle Engineering, Varna, Bulgaria, CIRP.
[14] Sundin, E., and B. Bras. 2005. Making functional sales environmentally and economically beneficial through product remanufacturing. Journal of Cleaner Production 13(9): 913–925.
[15] Adams W.M.; The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. Report of the IUCN Renowned Thinkers Meeting; 2006.
[16] Baines T.S., Lightfoot H.W., Evans S., Neely A., Greenough R., Peppard J., Roy R., Shehab E., Braganza A., Tiwari A., Alcock J.R., Angus J.P., Bastl M., Cousens A., Irving P., Johnson M., Kingston J., Lockett H., Martinez V., Michele P., Tranfield D., Walton I.M., Wilson H.; State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture; 2007. Vol.221, no.10, pp.1543-1552. doi: 10.1243/09544054JEM858.
[17] Garetti M., Rosa P., Terzi S.; Life Cycle Simulation for design of Product-Service Systems. Computer in Industry; 2012. Vol.63, pp.361-369.
[18] Garetti M., Rosa P., Terzi S.; Life Cycle Simulation for design of Product-Service Systems. Computer in Industry; 2012. Vol.63, pp.361-369.
[19] Favi C., Peruzzini M., Germani M.; A Lifecycle design approach to analyze the Eco-sustainability of industrial products and product-service systems. Proceeding of 12th International Design Conference; 2012. pp.879-888. ISSN 1847-9162; ISBN 978-95377-817-4.
[20] Xing K., Ness D., Lin F.; A service innovation model for synergistic community transformation: Integrated application of systems theory and product-service systems. Journal of Cleaner Production; 2013. Vol.43, no.0, pp.93-102.
[21] Pigosso D.C.A., McAloone T.C.; Maturity-based approach for the development ofenvironmentally sustainable product/service-systems. CIRP - Journal of Manufacturing Science and Technology; 2016, 15:33–41.
[22] M. Qu, S. Yu, D. Chen, J. Chu, B. Tian; State-of-the-art of design, evaluation, and operation methodologies in product service systems, Computers in Industry Volume 77, April 2016, Pages 1-14.
[23] Vasantha G., Roy R., Lelah A., Brissaud D.; A review of product-service systems design methodologies. Journal of Engineering Design, Taylor & Francis, 2012, 23 (9), pp.635-659.
[24] M. Lindahl, E. Sundin, Y. Shimomura and T. Sakao; An outline of an interactive design model for service engineering of functional sales offers. International design conference - design 2006 Dubrovnik – Croatia.
[25] Doran G. T.; There's a S.M.A.R.T. way to write management's goals and objectives. Management Review. AMA FORUM; 1981, 70 (11): 35–36.
[26] Eriksson H.E., Penker M.; Business Modeling with UML. New York; 2000.
[27] ISO, 2006a. 14040:2006 - Environmental management - LCA - Principles and Framework.
[28] ISO, 2006b. 14044:2006 - Environmental management - LCA - Requirements and Guideline.
[29] Ghose, A., Pizzol, M., McLaren, S.J., 2017. Consequential LCA modelling of building refurbishment in New Zealand-an evaluation of resource and waste management scenarios. J. Clean. Prod. 165, 119e133.
[30] Daddi, T., Nucci, B., Iraldo, F., 2017. Using life cycle assessment (LCA) to measure the environmental benefits of industrial symbiosis in an industrial cluster of SMEs. J. Clean. Prod. 147, 157e164
[31] Daddi, T., Nucci, B., Iraldo, F., 2017. Using life cycle assessment (LCA) to measure the environmental benefits of industrial symbiosis in an industrial cluster of SMEs. J. Clean. Prod. 147, 157e164
[32] Di Maria, A., et al. Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making. Waste Management (2018).
[33] J. Dong,Y. Chi,D. Zou, C. Fu, Q. Huang, M. Ni; Energy–environment–economy assessment of waste management systems from a life cycle perspective: Model development and case study. Applied Energy, Volume 114, February 2014, Pages 400-408.