Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 69 (2018) 499 – 504

www.elsevier.com/locate/procedia

25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark

Life cycle assessment of home smart objects: kitchen hood cases

Vincenzo Castorani[a]*, Marta Rossi[a], Michele Germani[a], Marco Mandolini[a], Alessio Vita[a]

[a] *Università Politecnica delle Marche, via Brecce Bianche, Ancona 60012, Italy*

* Corresponding author. Tel.: +39 071 2204797. *E-mail address:* v.castorani@pm.univpm.it

---

Abstract

Promoting a more sustainable and energy-saving economy is one of the main goal of the European Community. In this context, home appliance manufacturers are researching and developing more efficient and sustainable products. Home automation and smart objects, by implementing specific energy management strategies, can significantly reduce energy waste. This paper aims to investigate the benefits offered, in terms of environmental impacts, by a smart system for kitchen air treatment. The system is composed by two inter-connected smart devices: a kitchen hood and an additional aspiration system able to assure a constant indoor comfort minimizing energy consumption and heat losses. Three different configurations were analyzed and compared: conventional extractor kitchen hood, smart extractor kitchen hood, and smart filtrating kitchen hood with smart additional aspiration system. Results show that in comparison with a traditional hood, products equipped with smart devices present lower environmental impact, due to the optimization of their energy consumptions.

Keywords: life cycle assessment; air quality assessment; smart objects; household appliance; kitchen hood.

---

1. Introduction

In recent years, the promotion of a more sustainable and energy-saving economy has been one of the main goal of the European Community. In this context, the European Commission has repeatedly emphasized the significant role that ICTs (Information and Communication Technologies) can play in improving environmental and economical sustainability [1-3].

The growing integration of ICTs into everyday products has led to the notion of Smart Object (SO). A smart object is any daily product, equipped with sensors, memory and communication capabilities able to make informed decisions about itself and its use [4,5]. These decisions are based on data provided by its integrated technologies, about the surrounding environment and its state [6]. According to Lopez et al. [7], a SO possesses two or more of the following characteristics:

- unique identity and storage capability;
- sensing capacity, it is able to gain and provide information about the surrounding environment;
- actuating, it can control other devices by the way of actuation commands;
- decision-making, it is enabled to make informed decisions based on available information;
- networking, it is capable to communicate with other devices through wired or wireless technologies.

Smart objects can be successfully applied with different scopes, including an efficient and sustainable operation of home environment [8]. In this context, they aim to maintain indoor comfort with an efficient energy control by consuming energy only when and in the amount it is required, by recognizing and reducing energy waste and by implementing a proper management.

Generally, it is supposed that SOs improve the environmental sustainability of products [9]. Nevertheless, much research in recent years has also discussed possibilities

doi:10.1016/j.procir.2017.11.113

of increased damages. For instance, some studies [10-13] claim that both positive and negative environmental impacts should be expected from ICTs, and the real outcome will rely on how they are managed. Further, Eugster et al. [14] conclude that more research on this topic is needed because there are lots of evidences that both opportunities and threats are involved.

ICTs could help in improving environmental sustainability or worsening it; this leads to the conclusion that it is extremely important to assess environmental impacts of SOs. In the last years, the life cycle approach has been the most used methodology to perform this task. Life Cycle Assessment (LCA) allows the calculation of environmental loads of products, processes and services from raw material extraction to disposal/recycling phase.

Literature is broad about LCA of consumer products, but very few research is about smart household appliances. It is mainly limited to products such as computers and laptops, monitors, TVs and mobile phones [15].

In this context, this paper aims to enrich literature about environmental assessment of smart household appliances, investigating smart systems for kitchen air treatment. Moreover, nowadays, the product design should be focused toward eco-sustainability and customer's needs satisfaction [16]. In this regard, experimental tests have been conducted to assess how the main goal of the kitchen hood, namely maintain an adequate indoor air quality, is achieved.

The research question addressed in this paper is therefore: can smart devices improve the "environmental profile" of energy using products? Where "environmental profile" includes not only long terms impacts on environment, but also the evaluation of "social" aspects such as indoor air quality.

Three different configurations were analyzed and compared: conventional extractor kitchen hood, smart extractor kitchen hood, smart filtrating kitchen hood with smart additional aspiration system.

2. System description

The hood is one of the fundamental household appliances in a kitchen; it has the function to remove and treat fumes and vapors generated by cooking food. Based on the installation type, two different kinds of functioning can be distinguished: extracting and filtrating. The extractor hood directs cooking fumes and vapors outside through a duct connected to the outlet fan. The filtering hood, instead, is installed in a kitchen where there is no discharge to the outside: the air is purified by way of activated charcoal filters and recycled in the room.

Traditionally, the operation of a hood is manually handled by the user through electrical switches. However, recently, thanks to the introduction of ICTs, this appliance has been able to adjust the ventilation intensity based on information received by smart sensors systems. These systems, recognizing the air quality and the amount of steam generated during cooking, automatically adapt the performance of the hood, optimizing its operation. In addition, they switch off immediately the hood when it is no longer necessary to extract fumes, avoiding useless waste of energy.

The extractor hood is better than the filtering one. Indeed, by expelling exhaust air outside, it is able to constantly assure a high air cleanliness and the removal of cooking odors. However, with the aim of enhancing kitchen design and avoiding invasive interventions, it is often necessary installing a filtering hood. In order to improve its effectiveness and ensure a correct air recycling, this hood can be supported by a smart additional aspiration system that extracts outside exhaust air. This system, embedded with sensors that monitor the quality, humidity and air temperature, is able to work in connection with the hood. When the hood sensors detect fumes and/or strong smells, the system is switched on automatically, enhancing the indoor air quality.

In next sections, this paper is going to assesses sustainability and functioning of three different systems for kitchen air treatment:

1. System A: conventional extractor kitchen hood;
2. System B: smart extractor kitchen hood;
3. System C: smart filtrating kitchen hood with smart additional aspiration system.

2.1. Test procedure

In this paper, the functioning of the different hood configurations was directly tested during the preparation of a complete daily meal consumed by a two-member family [17]. The meal, considering the medium Italian portions, is composed by 160 gr of pasta, 100 gr of tomato sauce as condiment, 200 g of meat and 100 g of chips.

The measurements were carried out on a test bench installed in a laboratory with the following dimensions: 3 [m] height x 3,5 [m] x 4 [m].

The test bench consisted of the following equipment:

- kitchen hood able to work both in extracting and filtering mode, automatically (smart) or manually controlled;
- smart additional aspiration system (only in system C);
- induction hob and cookware;
- electrical energy meter;
- mass flow meter;
- commercial smart device able to assess air quality and cleanliness (Foobot® by Airboxlab).

The kitchen hood was installed at a height of 0,5 [m] from the induction hob. While, the Foobot® was positioned at the center of the room.

Sampling occurred over one cooking session for each scenario. In System A, the hood worked constantly at the maximum speed until 5 minutes after the end of cooking. In System B and C, the smart system modulated the fan speed of the cooker hood according to the air quality.

The aim of the testing campaign has been twofold. First assessing energy consumption and the expelled air mass flow. Second, evaluating indoor air quality and cleanliness during a daily cooking session.

It is important to underline that the expelled air mass flow plays a key role in the determination of use-phase consumption. Indeed, the depression generated within a kitchen, consequence of the air mass extraction, leads to the aspiration of outside air. This air, during the winter and summer period, should be properly thermally treated. That situation increases the room's thermal load and therefore energy consumption (methane and/or electricity).

3. Life cycle assessment

3.1. Goal and scope definition

The paper presents a comparative analysis of the LCA results of three different systems for kitchen air treatment according to the indications provided by regulations (ISO 14040 [18] and ISO 14044 [19]). The functional unit is defined as "to maintain good air conditions during the preparation of a complete daily meal consumed by a two-member family in Italy for 10 years". Daily meal is described in previous Chapter 2.1.

The system boundaries are defined as described in the following. The material extraction, manufacturing and End-of-Life (EoL) phases are included only for those components which are not common in all the considered systems, i.e., for System B: the electronic control devices and for System C: the electronic control devices and the additional aspiration system. This choice is justified by the following reasons:

- All the systems are equipped with the same traditional hood, therefore the impacts related to materials, manufacturing and EoL phases of the hood are the same in the three systems;
- Considering the Italian use scenario, the most affecting life cycle phase in terms of environmental impact for hoods is the use phase (Bevilacqua et al. [20]);
- The smart devices analyzed in this paper significantly affect the energy consumption phase, thus making interesting an analysis of how much their inclusion into an air treatment system allows gaining in environmental terms;
- The environmental impact of traditional hoods has been already studied in literature [20], while no studies exist for the new smart devices analyzed in this paper.

The use phase is included in the LCA analysis since energy consumptions and related impacts are different considering the three analyzed systems. The EoL phase is modelled following the approach proposed by the IEC/TR 62635 [21] and supposing a scenario of recycling for all the considered components. Foods used in the meal are not treated as part of the life cycle inventory: their impact is in fact independent by the employed air treatment systems. Outside the limits of the system boundaries: transport and maintenance phase. As the geometric dimensions and physical characteristics, the geographical location and distribution of markets and supply centers are expected to be the same for all the systems, the transportation phase from the manufacturing sites to the distribution centers and finally to each house is not included in the analysis. Furthermore, the environmental impact of transport phase is negligible if compared to the use phase [20].

The considered systems are expected to be free of maintenance across the selected lifespan of 10 years; therefore, the maintenance and service phases are not included in the analysis.

A cut-off in mass of 5 g has been applied to all the investigated products.

Concerning data sources, foreground system includes the manufacturing and the use phase, while background system includes the raw material extraction and the EoL phase. The manufacturer (an Italian cooker hood company) provided manufacturing data for the analyzed products. Moreover, for what concern the use phase, energy consumptions have been directly measured with instruments and experimental tests (as described in Chapter 2.1). Background data have been obtained from commercial databases (EcoInvent 3.1) and scientific literature.

3.2. Life cycle inventory

This section presents the information and data used for the LCA analysis of the three systems. The EcoInvent 3.1 database has been used.

3.2.1. Inventory data collection for raw material and manufacturing phase

The inventory related to raw material extraction and manufacturing phases for electronic control devices and aspiration system is presented in Table 1., where datasets for the used material categories are grouped. The allocation model chosen is the "Allocation, recycled content System Model" (Alloc, rec). In this model, recyclable materials are available burden-free to recycling processes [22]. Datasets used for materials and manufacturing processes refer to an unspecified location in the world (GLO). This choice derives from the fact the manufacturer produces and sells products in several geographic areas of the world.

Table 1. Datasets used for the material categories used.

EcoInvent 3.1 dataset for materials	EcoInvent 3.1 dataset for manufacturing processes
Acrylonitrile-butadiene-styrene copolymer {GLO}| market for | Alloc Rec, S	Injection moulding {GLO}| market for | Alloc Rec, S
Polypropylene, granulate {GLO}| market for | Alloc Rec, S	Injection moulding {GLO}| market for | Alloc Rec, S
Copper {GLO}| market for | Alloc Rec, S; Aluminium, primary, ingot {GLO}| market for | Alloc Rec, S; Steel, low-alloyed {GLO}| market for | Alloc Rec, S	N.A.
Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Rec, S	-
Electronic component, active, unspecified {GLO}| market for | Alloc Rec, S	-
Steel, chromium steel 18/8 {GLO}| market for | Alloc Rec, S	Sheet rolling, chromium steel {GLO}| market for | Alloc Rec, S; Deep drawing, steel, 650 kN press, single stroke {GLO}| market for | Alloc Rec, S; Metal working machine, unspecified {GLO}| market for | Alloc Rec, S
Magnetite {GLO}| market for | Alloc Rec, S	-N.A.
Flat glass, coated {GLO}| market for | Alloc Rec, S	-N.A.

3.2.2. Inventory data collection for use phase

Data related to the use phase have been derived by direct measures and therefore they can be considered as primary data.

Three tests, one for each system, have been performed to measure the energy consumption during the cooking of an

average daily meal. The experimental tests allow assessing the characterization of consumptions for the three analyzed systems, permitting to derive System A is the most energy consuming one, followed by System B and System C.
The background data used are the following:

- Electricity (for the cooker hood, air conditioning, additional aspiration system, and light functioning): Electricity, low voltage {IT}| market for | Alloc Rec, S;
- Heat produced by boiler: Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler atmospheric low-NOx non-modulating <100kW | Alloc Rec, S (where the boiler infrastructure has been excluded from the model)

3.2.3. Inventory data collection for EoL phase

The EoL treatments have been chosen among the “Recycling treatments” and “Landfill” categories of SimaPro software using Ecoinvent 3.1 database. Recyclable mass has been derived by following the IEC/TR 62635 [20] approach.

To include the recycling benefit obtainable by the reuse of materials, the recycled material has been included as “avoided product” in the EoL process modelling. The amount of avoided product respects the recyclability percentages provided for each material class in the IEC/TR 62635 [20] and follows the suggestions offered in the Ecoinvent DB.

For what concern the leftover parts and masses, which remain as disposal wastes, the following item has been used:

- Waste electric and electronic equipment {GLO}| market for | Alloc Rec, S.

3.3. Results assessment and interpretation

SimaPro 8.05.13 has been used as LCA software tool for the analysis as well as the EcoInvent database (version 3.1) has been used as supporting inventory database.

The environmental impacts have been calculated according to the following methods:

- ReCiPe mid-point - Hierarchist (H) version - Europe life cycle impact assessment (LCIA) [23];
- ReCiPe end-point - Hierarchist (H) version - Europe H/A - with the average weighting set (A) [23].

In particular, due to the fact that the investigated systems are energy consuming, energy and natural resources are predominant in this study. As a consequence, the analysis uses Human Health (HH) and Resources (RA) mid-point impact categories as well as Human Health (HH), Ecosystem quality (ED) and Resources (RA) end-point damage categories from the ReCiPe (H) method [23]. The climate change impact category within the ReCiPe mid-point (H) method includes all greenhouse gases specified in the Kyoto Protocol using global warming potentials from the IPCC Fourth Assessment Report with a 100-year time horizon [24]. The default used ReCiPe mid-point/end-point method perspective is the Hierarchist (H) version referred to the normalization values of Europe and based on the most common policy principles with regards to 100 [year] timeframe (as referenced in [19]).

At first, the impact results (after characterization) related to material and manufacturing phases of System C, i.e. the system equipped with a smart additional aspiration system, are shown in Fig.1. It is possible to notice that the main contribution in all the impact categories is due to the presence of electric and electronic components, i.e. wire harness, printed circuit boards and electric motor. This is related, especially for the Human toxicity, Metal depletion and Fossil depletion categories, to the deployment of precious and rare materials to manufacture such components.

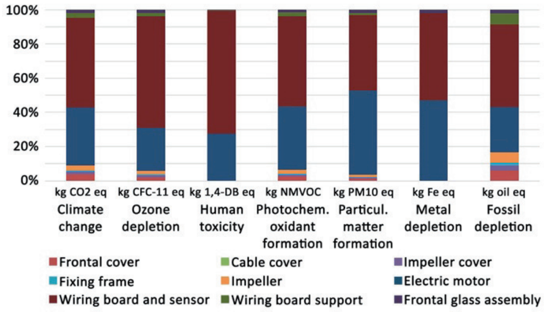

Fig. 1. Manufacturing and materials impacts of the additional aspiration system for the selected ReCiPe categories.

Considering the entire lifecycle of System C (Fig.2), the impacts of Manufacturing and Material phases are less than 10% of the total impact for all the categories except for Human toxicity and Metal depletion, thus underlining the importance assumed by electronic devices contained in System C.

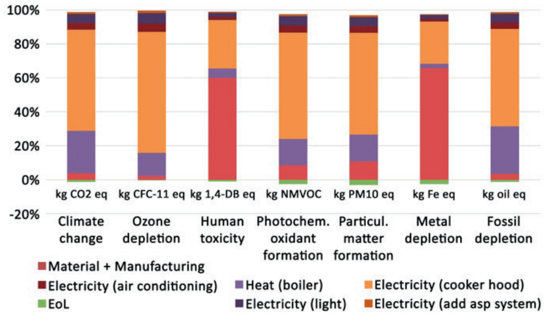

Fig. 2. Life cycle impacts of System C.

Analyzing the results (after characterization) of the entire life cycle of System C (Fig. 2), it is possible to derive the following observations:

- The use phase impact is predominant on the total impact;
- Among the different consumed energy typologies, the major impact is due to the hood functioning, followed by boiler, lights, air conditioning and finally the additional aspiration system;
- The EoL phase for the analyzed components (EoL of the entire hood is not included in the analysis) has a negligible impact (less than 3% of the total life cycle impact).

The results of the entire life cycle impacts of System B (Fig. 3.) show comparable trends with the previous ones, except for a different reciprocal weight of energy consuming components. In this case, in fact, the major impact is due to the hood functioning, followed by the boiler, the air conditioning, and finally lights. The reasons are connected to the higher quantity of air expelled, and the consequent treatment which it needs.

The results (after characterization) obtained for life cycle impacts of System A are similar of those ones of System B.

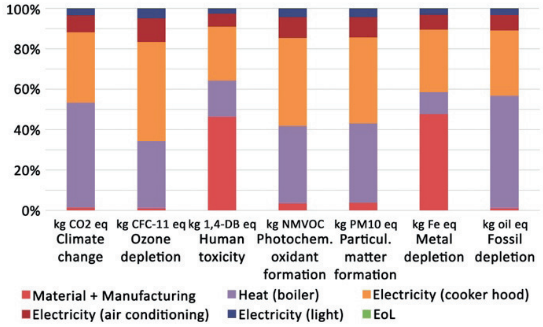

Fig. 3. Life cycle impacts of System B.

Fig.4 shows the results for the three systems in terms of mid-points. For Climate Change and Fossil Depletion impact categories, System C is the best solution, followed by System B and A. Results are opposite in case of "Human Toxicity" and "Metal Depletion" impact categories, where the best solution is System A, followed by System B and C. The presence in these two last systems of electric and electronic components cause these higher environmental impacts in these related impact categories.

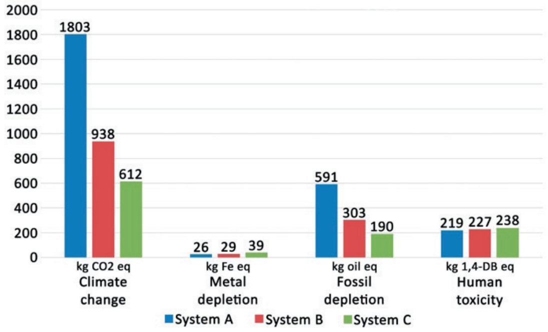

Fig. 4. Comparison of the systems for the ReCiPe mid-points.

However, analyzing end-points for the three damage categories (Fig.5), System C is the best one in terms of environmental impact, followed by System B and System A.

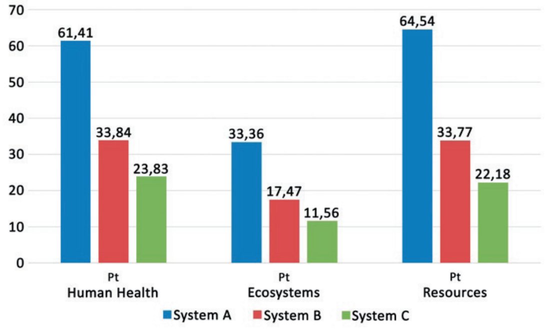

Fig. 5. Comparison of the systems for the ReCiPe end-points.

The possibility to activate the cooker hood and to adequate its speed based on real needs and the cut of extracted air, determine a significant reduction of energy consumption, leading to a minor environmental impact.

In particular, it is possible to obtain a reduction of about 40% passing from System A to System B and a further reduction of about 30% passing from System B to System C.

4. Air quality assessment

In this study, Foobot® by Airboxlab was used to assess kitchen air conditions. This device is able to measure 5 different physical quantities:

1. temperature [°C];
2. relative humidity [%];
3. level of carbon dioxide CO_2 [ppm];
4. level of volatile organic compounds VOC [ppb];
5. level of particulate matter $PM_{2.5}$ [$\mu g/m^3$].

In particular, CO_2, VOC and $PM_{2.5}$ levels have been analyzed to draw the appropriate conclusions. The World Health Organization – WHO defined the following threshold values for indoor air pollution: 800 [ppm] for CO_2, 300 [ppb] for VOC and 25 [$\mu g/m^3$] for $PM_{2.5}$.

The experimental tests highlighted that the extractor hoods ensure better air quality than the filtering ones. The additional aspiration system, although it enhances air quality, is not adequate to achieve levels comparable to those of the aspirating hoods. The expelled air mass is too far from the values drawn by the extractor hoods.

In addition, manual operation has allowed to maintain better environmental conditions than smart operations. However, this last result is related to the chosen speed (air flow rate setting) for the manual functioning: a lower speed could lead to different results. Specifically, Fig. 6 shows the minutes in which the threshold values have been exceeded in the various scenarios.

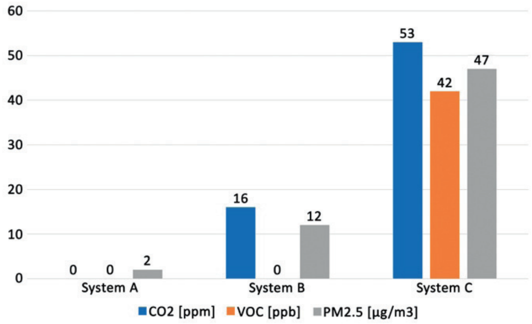

Fig. 6. Minutes exceeded WHO thresholds for the different systems.

Cooking tests last for each System: 95 [min] for System A, 92 [min] for System B and 103 [min] for System C. The different duration of the tests relates to the fact that, to restore a good air quality, it is necessary to keep the system running after the cooking is finished. This switching-off time is function of the air quality at the end of the cooking and the type of system (conventional or smart).

5. Discussion

Results presented in previous sections show the environmental and air quality assessment of three different systems for air treatment in the kitchen environment.

Environmental impacts have been expressed by means of ReCiPe impact assessment method both at mid-point and end-point level, while the analysis of air quality parameters is based on World Health Organization suggestions.

The interesting research question addressed was: can the use of smart devices increase the environmental performances of energy using components? What emerges is that, from a general perspective, the introduction of strategies for the reduction of the energy consumed along the entire product life cycle determines a significant contraction of the related impacts. However, if specific impact categories are observed (e.g. in this case "Human Toxicity" and "Metal Depletion"), the use of electric and electronic components weights adversely on the environmental behavior. Furthermore, for the analyzed cases, the decrease of energy consumption comes at the expense of good air conditions, which are penalized from lower aspiration flow and reduction of air exchange.

According to the current analyzed product configurations, from an environmental point of view, the use of certain materials, such as rare and precious metals, should be reduced. In parallel, strategies to consider also further "environmental" parameters need to be carefully adopted in the development of smart devices, thus avoiding "impact" transfer, which cannot be neglected in a wide concept of environmental sustainability.

6. Conclusion

This paper aims to enlarge literature about the assessment of smart objects from an "environmental" point of view. Where "environmental" term is intended in a broad sense, including not only environmental impacts, but also the evaluation of "social" impacts. In particular, three different configurations of kitchen hoods were assessed: conventional extractor kitchen hood, smart extractor kitchen hood and smart filtrating kitchen hood with smart additional aspiration system.

Results showed that the best solution in term of environmental performance (System C) is not the best solution if "social" aspects (maintaining a good air quality and cleanliness) are considered. Indeed, the configuration that allows to reach the most excellent air quality indexes is System A. A trade-off is necessary for identifying the best "environmental" configuration.

Future works will consist in repeating the tests to verify results reproducibility and in analyzing different management strategies of the conventional hood (lower speed, variable speed, etc.) or the cooking of various daily meals. Moreover, system boundary could be enlarged to take into consideration also the manufacturing of the hood and the transport phase.

References

[1] Communities, C.O.T.E., Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on mobilising Information and Communication Technologies to facilitate the transition to an energy-efficient, low-carbon economy. COM 2009, 111 final.

[2] European Commission. Commission recommendation of 10 October 2014 held on the data protection impact assessment template for smart grid and smart metering systems (2014/724/EU). Off. J. Eur. Union 57.

[3] High-Level Advisory Group, REEB Consortium. ICT for a Low Carbon Economy. Smart Buildings, European Commission Directorate-General information, society and media. 2009.

[4] Ferguson GT. Have your objects call my objects. Harvard business review 2003; 80(6), p. 138-143.

[5] Gellersen HW, Schmidt A and Beigl M. Adding Some Smartness to Devices and Everyday Things. Proc. of WMCSA 2000 – 3rd IEEE Workshop on Mobile Computing Systems and Applications, December 2000, IEEE Computer Society 2000, Monterrey, USA.

[6] Ziefle M, Rocker C. Acceptance of pervasive healthcare systems: A comparison of different implementation concepts. 4th Intern. Conf. on Pervasive Computing Technologies for Healthcare. 2010; 1(6), p. 22-25.

[7] López TS, Ranasinghe DC, Patkai B, McFarlane D. Taxonomy, technology and applications of smart objects. Inf Syst Front; 3(2), p. 281-300.

[8] Papetti A, Iualè M, Ceccacci S, Bevilacqua R, Germani M, Mengoni M. Smart Objects: An Evaluation of the Present State Based on User Needs. Lecture Notes in Computer Science 2014; 8530, p. 359-368.

[9] Erdmann L, Hilty L. Scenario analysis: exploring the macroeconomic impacts of information and communication technologies on greenhouse gas emissions. Journal of Industrial Ecology; 14(5), p. 826–843.

[10] Hilty LM, Arnfalk P, Erdmann L, Goodman J, Lehmann M, Wäger PA. The relevance of information and communication technologies for environmental sustainability – a prospective simulation study. Environmental Modelling & Software 2006; 21(11), p. 1618-1629.

[11] Røpkea I, Christensenb HT. Energy impacts of ICT - insights from an everyday life perspective. Telematics Inform. 2012; 29(4), p. 348-361.

[12] Watson RT, Corbett J, Boudreau MC, Webster J. An information strategy for environmental sustainability. Commun. 2012; 55(7), p. 28-30.

[13] Melville N, Whisnant R. Energy and carbon management systems: organizational implementation and application. J. Ind. Ecol. 2014; 18 (6), p. 920-930.

[14] Eugster M, Hischier R, Duan H. Key Environmental Impacts of the Chinese EEE-Industry: A Life Cycle Assessment Study. Empa/Tsinghua University, Switzerland/China, 2007.

[15] Arushanyan Y, Ekner-Petersen E, Finnveden G. Lessons learned - Review of LCAs for ICT products and services. Comp. in Industry 2014; 65 (2), p. 211-234.

[16] Papetti A, Germani M, Mandolini M. Product innovations and eco-sustainability: an approach to evaluate the relationships. Key Engineering Materials 2014; 572, p. 74-77.

[17] LARN, Livelli di assunzione di riferimento di nutrienti ed energia per la popolazione italiana, Società Italiana di Nutrizione Umana - SICS, 2014.

[18] ISO-International Organization for Standardization. Environmental management - Life cycle assessment - Principles and framework. ISO EN 14040, Geneve, July 2006.

[19] ISO-International Organization for Standardization. Environmental management - Life cycle assessment - Requirements and guidelines. ISO EN 14044, Geneve , July 2006.

[20] Bevilacqua M, Caresana F, Comodi G, Venella P. Life cycle assessment of a domestic cooker hood. J. of Clean. Prod. 2010; 18, p. 1822-1832.

[21] IEC-International Electrotechnical Commision. Guidelines for end-of-life information provided by manufacturers and recyclers and for recyclability rate calculation of electrical and electronic equipment. IEC TR 62635, October 2012.

[22] Nicholson AL, Olivetti EA, Gregory JR, Field FR, Kirchain RE. End-of-life LCA allocation methods: Open loop recycling impacts on robustness of material selection decisions. Sustainable Systems and Technology 2009, IEEE International Symposium.

[23] Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J, van Zelm R. ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation - First edition.

[24] IPCC. Climate change 2007: the physical science basis. Contribution of Working Group I to the IV Assessment Report of the Intergovernmental Panel on Climate Change. Solomon S, Qin D, Manning M. et al.