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Environmental assessment of microwaves and the effect of European energy efficiency and waste management legislation

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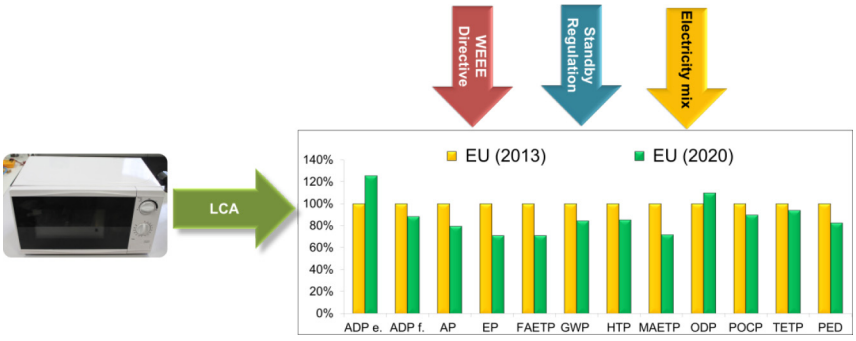
HIGHLIGHTS

- 130 M microwaves in the EU consume 9.4 TWh of electricity annually.
- First LCA for microwaves to estimate the environmental effects of EU regulation
- Standby Regulation will reduce impacts by 4–9% by 2020; WEEE Directive by ~0.3%.
- Decarbonisation of electricity will reduce most impacts by 6–24% by 2020.
- Eco-design regulation for microwaves should be developed to reduce resource use.

GRAPHICAL ABSTRACT



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ABSTRACT

More than 130 million microwaves are affected by European Union (EU) legislation which is aimed at reducing the consumption of electricity in the standby mode ('Standby Regulation') and at more sustainable management of end-of-life electrical and electronic waste ('WEEE Directive'). While legislation focuses on these two life cycle stages, there is little information on the environmental impacts of the entire life cycle of microwaves. To address this gap, this paper presents a comprehensive life cycle assessment of microwaves and assesses the environmental implications of the Standby Regulation and the WEEE Directive at the EU level. The impacts are first considered at the level of individual appliances and then at the EU level, with the aim of evaluating the potential environmental implications of the full implementation of the above two EU regulations by 2020. The effects of the electricity decarbonisation and the expected increase in the number of microwaves in use have also been considered. The results suggest that implementation of the EU regulation by 2020 will reduce the environmental impacts considered by 4%–9% compared to the current situation. The majority of these reductions is due to the Standby Regulation, with the contribution of the WEEE Directive being small (~0.3%). However, the expected decarbonisation of electricity will result in much higher reductions (6%–24%) for most impact categories. The results also show that the materials used to manufacture the microwaves, the manufacturing process and end-of-life disposal are environmental hot-spots for several impacts, including depletion of abiotic elements. Therefore, efforts to reduce the environmental impacts of a future electricity mix should be combined with the development of specific eco-design regulations for microwaves that stipulate optimisation of resource consumption. Possible future trends, such as shorter lifetimes and limited availability of some resources, make the development of such product regulations more critical.

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1. Introduction

Rapid technological developments and falling prices are driving the purchase of electrical and electronic (EE) appliances in Europe (EEA, 2014). Consumers also tend to buy new EE appliances before the existing ones reach the end of their useful life as electronic goods have become fashionable and 'status' items (Mansfield, 2013). As a result, discarded EE goods are one of the fastest growing waste streams worldwide (EEA, 2014). A further issue associated with their growing consumption is the increase of household electricity consumption in most EU countries over the last decade, despite many appliances being more energy efficient (Eurostat, 2016).

EE goods generate environmental impacts in all stages of their life cycle (Andrae and Andersen, 2010). This has been demonstrated by many authors who have analysed life cycle impacts of different devices using life cycle assessment (LCA) as a tool. Some examples include LCA studies of plasma TVs carried out by Feng and Ma (2009), Hischier (2015) and Hischier and Baudin (2010). Life cycle impacts of computers have been evaluated by Choi et al. (2006), Duan et al. (2009) and Jönbrink (2007). Examples of studies of electrical devices include an LCA of refrigerators (Monfared et al., 2014), dishwashers (Johansson and Björklund, 2010), washing machines (Presutto et al., 2007b) and vacuum cleaners (Gallego-Schmid et al., 2016).

However, for microwaves, only screening LCA studies have been carried out so far, with most being based on generic or outdated data and assumptions. For instance, Jungbluth (1997) assessed the life cycle environmental performance of different cooking devices, including microwaves, in Switzerland and Germany. The study published generic aggregated inventory data for microwaves, but no specific results were given for the microwaves as the analysis focused on the comparison of electric, gas and wood ovens. Moreover, the inventory data are now 20 years old and can be considered outdated. Another study (Devuono et al., 2000) compared environmental performance of cooktops, ovens and microwaves, but focused only on CO_2, SO_2 and NO_x emissions from electricity consumption in the use stage. In 2002, the National Environmental Technology Information Centre of Korea published the product category rules for microwaves with the aim of developing Environmental Product Declarations (EPDs) from a life-cycle perspective (APEC-VC Korea, 2002). A set of general rules were established to make EPDs comparable, but no specific inventory data or guidelines for data collection were included, except for the definition of a standard scenario to calculate the environmental impacts of the use stage. Finally, the Bio Intelligence Service in association with ERA Technology (Mudgal et al., 2011a) performed a technical, environmental and economic analysis of domestic and commercial ovens, as a preparatory study for the development of EU eco-design and energy labelling regulations, both of which aim to improve energy efficiency of energy-using products. In their study, Mudgal et al. (2011a) carried out screening LCA studies for 10 types of electrical oven, including microwaves. Although this work represents the most complete LCA study of microwaves so far, it relied on aggregated inventory data and general assumptions on the consumption of materials and product manufacture. Furthermore, only five environmental impacts were considered (eutrophication, acidification, global warming, ozone layer depletion and primary energy demand), in addition to some air emissions and heavy metals, which were estimated at the inventory level only. The authors concluded that use of microwaves was the only environmentally relevant life cycle stage, suggesting that minimising power consumption in the standby mode was the only cost effective alternative to improving their energy efficiency, as they are a mature product with limited room for additional improvements (Mudgal et al., 2011a). Based on these conclusions, and given that microwaves were already included in the EU regulation (No. 1275/2008) to reduce power consumption in the standby mode (European Commission, 2008), they were excluded from the eco-design and energy labelling regulations (Nos. 66/2014 and 65/2014, respectively) for domestic ovens, hobs and range hoods (European Commission, 2014a, 2014b).[1]

However, some other authors have argued that it is likely that the importance of the use stage for the environmental impacts has been overestimated in the European eco-design regulations for some devices, such as televisions, monitors and computers (WRAP, 2010; van Rossem and Dalhammar, 2010; Huulgaard et al., 2013). As a result, this has obscured the relative importance of other life cycle stages, particularly the production process and the materials used for the manufacture of electrical and electronic devices. To address this issue, WRAP (2010) specifically recommended that life cycle inventory (LCI) for microwaves should be improved for these two life cycle stages. According to the authors, the available LCI data are limited, incomplete or insufficient, preventing a reliable characterisation of the environmental footprint of these appliances.

The raw materials extraction and processing stages have been gaining importance in recent years in terms of their contribution to the environmental impacts of microwaves. This is due to their lower life expectancy, which decreased from 10 to 15 years in the late 90s to 6.5–8 years nowadays (Dindarian and Gibson, 2011; Huisman et al., 2008; Mudgal et al., 2011a). The main reasons for this trend are faster product innovation cycles and the recent EU 'Standby Regulation' to reduce standby electricity consumption in the use stage (European Commission, 2008). Given that microwaves account for the largest percentage of sales of all type of ovens in the EU, with a stock of 125 million units in 2007 and a predicted stock of nearly 135 million units by 2020 (Mudgal et al., 2011a), it is increasingly important to start addressing their impact on resource use and end-of-life waste.

The latter is growing rapidly in many parts of the world. In the EU, 184,000 t of waste electrical and electronic equipment (WEEE) were generated in 2005 from microwave ovens (Huisman et al., 2008) with >195,000 t (16 million units) expected to be sent for disposal in 2025 (Mudgal et al., 2011a). To cope with the problem of the growing EE waste, the WEEE Directive provides the European regulatory framework to prevent, re-use, recycle and/or recover this type of waste (European Parliament, 2012). It also aims to improve the environmental performance of operators in the supply chain of EE equipment, including producers, distributors and consumers and, in particular, those collecting and treating WEEE. Thus, any achievements in waste prevention and minimisation would contribute directly to improving resource efficiency. The latter underpins the *Europe 2020* strategy, which aims to contribute to Europe's smart, sustainable and inclusive economy (European Commission, 2010).

However, so far, there has been no comprehensive study of environmental impacts of microwaves over their whole life cycle and hence their environmental impacts beyond the use stage remain largely unknown. Similarly, there is a lack of knowledge about the effects on the impacts of the EU regulation related to reducing energy use in the standby mode and end-of-life waste. To address these gaps, the main goals of this study are:

- to estimate the environmental impacts of the whole life cycle of a microwave, identify life cycle stages that contribute most to the impacts ('hot-spots') and suggest possible improvement options; and
- to assess the implications at the EU level of the implementation of the Standby Regulation (European Commission, 2008a) and the WEEE Directive (European Parliament, 2012) and provide guidance on future research and policy making.

To our knowledge, this is the first study of its kind internationally.

2. Methods

The environmental impacts of microwaves have been evaluated through LCA, following the guidelines specified in the ISO 14040/44

[1] Microwave ovens are only included when associated with an electric or gas domestic oven (i.e. appliances which have 'microwave heating' as a primary cooking function are not included).