Household Appliance Lifecycle and Sustainable Development

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Abstract. Economic growth is stimulated by a continuous increase in goods consumption. With regard to household appliances it manifests itself in its frequent replacement. This may have an impact on negative environmental and climatic changes. In this article, the authors deal with this problem in the context of consumer awareness of the impact of their behavior on these changes. The aim of the article is to check whether frequent replacement of household appliances is justified from the point of view of environmental pollution and climate protection. The article highlights not only the carbon footprint of two types of devices, but also consumer preferences for replacing old devices with new ones. As part of the research, a questionnaire was conducted on the frequency of replacement of household appliances and the reasons for their replacement. An analysis and comparison of the carbon footprint of two refrigerators - the old type and in line with the latest energy consumption standards - was carried out. It was found that the replacement of the refrigerator, due to the lower electricity consumption in the use phase, is ecologically profitable compared to the old type refrigerator after 8 years of use.

Keywords: Carbon footprint · Life Cycle Assessment · Environmental impact

1 Introduction

Household appliances were used in the past longer than today. The main reason was the high purchase price. Today, along with the increase in availability, this equipment has become relatively cheap, and consumers replace it relatively often – often more than is justified. It is commonly believed that this poses a significant threat to the implementation of a sustainable development strategy [1, 2].

The negative impact of household goods on the natural environment begins at the production stage, where many factors potentially threaten the natural environment, including:

– consumption of raw materials (metals, paints, glues, etc.)
– media consumption (water, energy)
– fossil fuel consumption (natural gas, heating oil)
– emission of pollutants into water and air
– waste generation

A. Hamrol et al. (Eds.): MANUFACTURING 2022, LNME, pp. 203–213, 2022.
https://doi.org/10.1007/978-3-031-00218-2_17

The mentioned environmental impacts are limited by a number of legal provisions. Production plants are required to update their permits in the event of launching a new installation, introducing new packaging or changing the preparations used.

The use of household appliances also has a negative impact on the natural environment, mainly due to energy consumption. The consumer is informed about this aspect of using the equipment via the energy label. One of the goals of its introduction was to influence consumer natural environment-oriented decisions about the choice of equipment.

The first energy labels appeared on cooling equipment in the 90s, and the E energy efficiency class was the dominant one. As a result of technological progress, the equipment achieved better and better classes over the next years. When the standard scale turned out to be insufficient, a plus sign was added to the classes. In this way, well-known classes such as A+, A++, A+++ were created. In the second decade of the 21st century, the classification method presented above became inadequate. In order to create space for further technological development, the European Commission decided to upscale energy efficiency and return to the original A-G scale [3]. The introduced change is to ensure better legibility of the labels. The new formula became valid on March 1, 2021 for three types of appliances: refrigeration equipment, dishwashing machines and washing machines. The most energy-efficient devices remain in the "green" class, and those with lower energy efficiency in "orange" and "red" classes. In practice, the green class is empty today and is waiting for new technological challenges of energy-saving and environmentally friendly solutions.

The lifetime of household appliances varies greatly. It depends to a large extent on the individual attitudes of consumers. However, the policy of producers also has a significant influence on lifetime [4]. In general, there is a noticeable tendency to shorten the life of household appliances. Technological development and fashion in a given industry force the displacement of old products in favor of new ones. This is caused by their wear or the growing expectations as to the effectiveness of the product. This is directly related to the marketing definition of a product life cycle, which says that a product is offered on the market as long as there is a demand for it [5].

Enterprises more and more commonly pursue a policy of purposefully shortening the life of household appliances, known as planned obsolescence (planned aging of products) [6]. It consists in introducing new, more technologically advanced equipment to the market, which at the same time displaces older equipment from the market (not necessarily worse) [7–9]. For this purpose, various marketing campaigns are used to motivate consumers to buy new products. In the case of electronic equipment, this is also achieved by programming that causes the equipment to stop working after a certain period of time or after a certain number of cycles. Such situations usually take place after the warranty has expired. In dishwashers or ovens, a way to deteriorate the operation of equipment after a certain period of time is to use components which, as a result of regular exposure to high temperature, wear out with a certain intensity [10].

The introduction of new regulations, which force changes and causes the removal of older equipment from the market, also works in a similar way to the planned obsolescence. Consumers voluntarily replace older, functional equipment with newer equipment. In addition to the requirements of the European Union regulations, customer requirements remain an important issue. The growing awareness of consumers has caused an increase in both the quality requirements and the requirements for the production and disposal of the purchased products [11, 12].

After the operation stage, household appliances in most cases are handed over by consumers to electronic waste collection points, which pass them for disposal or recycling. The basic stage of recycling is manual disassembly of each product. This allows for the removal of hazardous components and the segregation of reusable parts. The procedures of disassembly vary depending on the type of equipment as well as the number of hazardous components. The materials used in the product are recovered depending on the ease, cost and possibility of later development. In many cases, metals are collected first, then plastics, and finally composite materials and laminates. Materials are sorted according to shape, size and density.

The law imposes other obligations on producers related to environmental protection, consisting in achieving an appropriate level of recycling and recovery of:

- used electric devices and electronics
- packaging waste
- used batteries
- used oils

A separate issue is the repair of broken or damaged equipment. Theoretically, it should benefit consumers, first of all, and the natural environment through lower waste generation and better use of resources.

The research conducted in Rosko 2018 shows that 64% of respondents always repair equipment that has failed. The main reason why consumers did not repair the equipment turned out to be the high price of the repair. The other reasons are the preference to obtain new equipment and the feeling that the old equipment was outdated or obsolete [13]. The research identified the following elements that limit the availability of repair:

- lack of access to spare parts, technical information, diagnostic software and training, especially for independent repair shops; failure to ensure the availability of spare parts throughout the life of the equipment by the manufacturer
- no standardization of key components between brands (in particular, this applies to household appliances) or between appliances of the same brand,
- lack of technical knowledge necessary to carry out the repair due to the increasing complexity of equipment and the increasing share of electronic components and their miniaturization
- equipment design that prevents repair (e.g. disassembly of glued elements, welded plastic elements in washing machines, inaccessible screws, or non-standard screws)
- unattractive repair price due to the high cost of labor - often producing new equipment based on mass production is cheaper for the manufacturer

The research also highlighted the low profitability of hardware repair companies, which makes it more difficult for consumers to access such services.

2 Objectives of the Work and Research Method

The considerations presented in the introduction allow for the formulation of the following conclusions:

– consumers are replacing household appliances more and more often because they want to, because they can afford it, and because they are forced to do so by the manufacturer's policy of deliberately reducing the durability of the equipment
– it is not profitable for consumers to repair damaged equipment because it is either technically impossible or unprofitable
– equipment is becoming more energy efficient and more environmentally friendly

Therefore, the question arises whether the observed shortening of the service life of household appliances by manufacturers is justified economically and environmentally. The research described in this article aims to answer at least a part of this question.

The research was carried out in two stages. In the first stage, questionnaire research was carried out, the purpose of which was to obtain answers to the following questions:

– After what period of use do consumers replace household appliances?
– What are the reasons for replacing the equipment?

A special and structured research questionnaire was prepared. The questions were limited to the so-called large household appliances (e.g. refrigeration equipment, cooking equipment, washing and drying equipment).

A seven-point scale was used in the lifetime responses: from less than 1 year to more than 15 years. The questions relating to the reasons for the exchanges contained seven possible options to choose from, selected by the authors on the basis of their experience:

– malfunction
– home renovation
– high energy consumption
– lack of functions
– furnishing a new home
– the equipment is outdated
– aesthetic considerations

The respondents could select any number of responses. The survey was carried out using Google Forms in the period of May 1–August 8, 2021. A group of 465 respondents took part in the survey.

A refrigerator was selected as a representative of household appliances for the second stage of the research. Its environmental impact throughout its life cycle has been determined for production and use stage. Two types of refrigerators differing in technological advancement and energy consumption were considered.

The most common idea to measure the environmental impact is product carbon footprint (PCF). Product Carbon Footprint is the amount of carbon dioxide or its equivalent released to the atmosphere during all Life Cycle Assessment of the given product [14].

Because emissions during the production process are not only CO_2, other gases have been converted into CO_2eq with the indicator of global warming potential (GWP) in comparison to carbon dioxide [15]. The use of such a conversion factor allows for the unification of the results, regardless of the type of emission that occurs in a given process. The use of one unit in the form of CO_2Eq allows you to compare with each other not only similar products, as in the example below, but also products or processes significantly different from each other.

The calculations were based on the data available in the literature on GHG emission, energy consumption as well as ready CO_2eq emission indicators for raw materials, production processes and energy use [16, 17]. In all processes, indexes and values are based on the European Union economy, which is adequate for the production processes carried out in the European Economic Community (EEC). The calculations refer to the energy consumption for the production of individual components described in Table 1, but also to the total energy consumption in the production plant where the refrigerators described in the example were produced. This allows for a relatively accurate description of the impact of individual pieces of product, taking into account the maintenance of machinery and equipment, buildings or design, and planning work in the factory. For manufacturing processes, the CO_2eq has been adopted at the level of 0.836 – the factor calculated for Poland in 2017 [18].

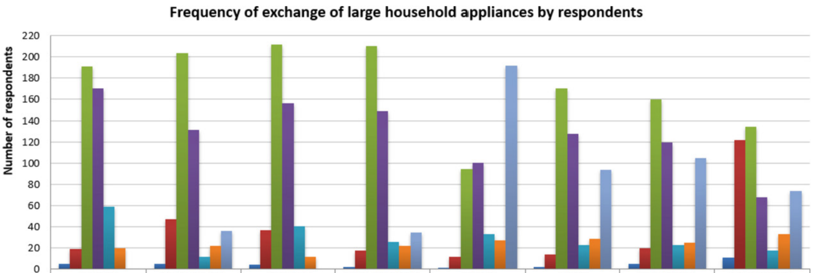
In the last stage, it was analyzed how long the purchase of a new refrigerator with high energy efficiency pays off from the point of view of the consumer and the natural environment. This allowed assessment of whether the period after which consumers most often replace refrigerators is justified from the presented points of view.

3 Results of Consumer Surveys

In response to the question about the lifetime of household appliances, the answer that received the most votes was the range "average (5–10 years)", followed by the answer "quite rarely (10–15 years)". Microwave ovens were an exception, where the second answer that received the most votes from the respondents was "quite often (1–5 years)". The frequency and reasons for replacing various household appliances are described in Fig. 1.

In response to the question about the reasons for replacement of equipment, the most common answer was "failure". The second most common answer was the renovation of the kitchen/apartment/house, and the third most common answer was high energy consumption. The answer with the fewest indications was aesthetic considerations. The reasons for the replacement of household appliances are described in Fig. 2.

The economic analysis of potential customers was not taken into account because the amount of income of a given household does not translate into the impact of the equipment used on the natural environment and climate. The subject of the research was the direct impact of the household appliances used on the environment. The analysis of ecological behavior of consumers in relation to their earnings may constitute a separate topic.



	FRIDGE	DISHWASHER	WASHER	KITCHEN HOOD	STOVE	OVEN	COOK PLATE	MICROWAVE
Often (< 1 year)	5	5	4	2	1	2	5	11
Quite often (1 - 5 years)	19	47	37	18	12	14	20	122
Average (5 - 10 years)	191	204	212	210	95	170	160	135
Quite rarely (10 - 15 years)	170	132	156	149	101	128	120	68
Rarely (> 15 years)	59	12	41	26	33	23	23	18
I do not change	20	22	12	22	27	29	25	33
Not applicable	0	36	0	35	192	94	105	74

Fig. 1. Frequency of large household appliance replacement.

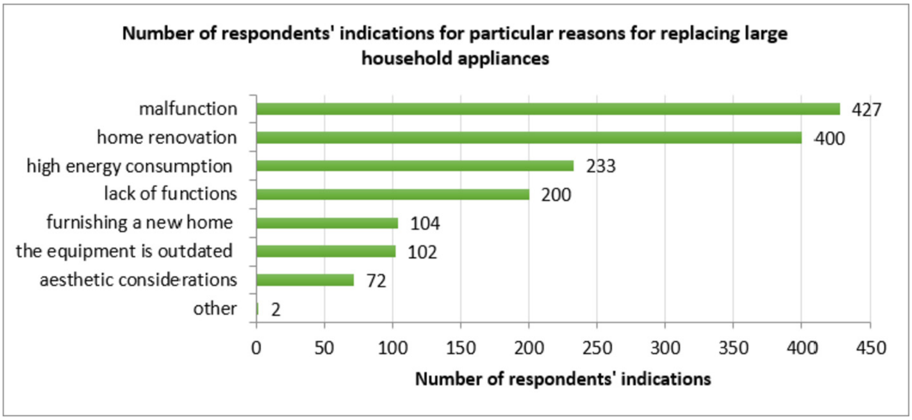


Fig. 2. Reasons for replacing large household appliances.

4 Carbon Footprint Analysis

The survey results suggest that it is advisable to ask the question: after how many years it pays off to replace old equipment with new one, taking into account that the new equipment is more energy-efficient than the old one, but its production causes an additional burden on the environment.

To reply to this question, an analysis of the carbon footprint was used.

A refrigerator was selected for comparative analysis because it consumes the most energy of other equipment due to working continuously. Two types of refrigerators were selected based on the European Union energy consumptions scheme – one with the lower energy efficiency class “F” and the second with the higher class “C”.

The following assumptions were made:

– two built-in refrigerators (for domestic use) in energy classes “F” and “C”
– a trouble-free life cycle of both refrigerators - no part replacement, repair and refrigerant escape
– similar CO_2 emissions related to the transport of equipment - will be wrinkled in comparative analysis
– similar CO_2 emissions related to recycling - due to a similar construction of both equipment, the values obtained would be close - will be omitted in the comparative analysis

Emissions during production are the sum of the partial carbon footprints for semi-finished products and the refrigerator parts, and the carbon footprint of the energy use in the factory that produces the refrigerator. Partial carbon footprints are marks for a specific component made of a known material. The estimated weight of a component was multiplied by the value of the benchmark, thus obtaining its carbon footprint. All partial carbon footprints were summed [19–21].

The amount of CO_2 emissions directly related to production processes was calculated on the basis of the total amount of energy used in the factory and the production volume. This approach allowed to take into account all direct and indirect sources of energy consumption. Thanks to this, the carbon footprint of the presented products includes elements such as maintenance of machinery, internal transport or maintenance of buildings in which the production process takes place.

The unit energy consumption per 1 refrigerator was determined, and then, knowing the amount of energy consumed in the plant, the total amount of CO_2 emitted was estimated. Annual emission of CO_2 equivalents was calculated by multiplying CO_2 emission per kWh for Poland and the electricity consumption for both refrigerators. The service life was set at 10 years and multiplied by the indirect annual emissions resulted in the total lifetime CO_2 emissions of both refrigerators.

The CO_2 emissions during production for both refrigerators - in the higher and lower energy efficiency classes - are similar. On the other hand, when comparing the CO_2 emissions resulting from use, the refrigerator in the higher energy efficiency class, class “C”, was almost twice as low, which in turn translated into twice lower emissions throughout its life cycle.

Taking into account the environmental impact of both the production and use of a new refrigerator in energy efficiency class “C”, compared to the old device in class “F”, it can be recognized when the given values balance. If you consider the option of using an existing refrigerator, the indirect emission of which is 240 kg CO_2eq, and the purchase of a new one, the production of which will emit 917 kg CO_2, and the annual use of 123.7 kg CO_2eq, the replacement pays off after 8 years of use. If it is necessary to buy a new refrigerator, it is generally advisable to buy a device in the best energy efficiency class possible, because CO_2 emissions in the production process are largely similar for all types of devices. The replacement balance of an already owned refrigerator is shown in Fig. 3.

Table 1. Fridge production and use carbon footprint [19–21]

		Fridge in a lower energy efficiency class				Fridge in a higher energy efficiency class			
	Volume	267 L				264 L			
	Energy efficiency class	F				C			
	Dimensions [cm]	175.5 × 54 × 55				175.5 × 54 × 55			
	Element	Raw material	Weight [kg]	Emission index CO_2 [CO_2/kg]	Partial carbon footprint [CO_2/kg]	Raw material	Weight [kg]	Emission index CO_2 [CO_2/kg]	Partial carbon footprint [CO_2/kg]
Raw material	Casing	Stainless steel	14.5	6.15	89.2	Stainless steel	14.5	6.15	89.2
	Assembly reinforcements	Carbon steel	1.0	1.77	1.8	Carbon steel	1.0	1.77	1.8
	Hinges	Stainless steel	1.2	6.15	7.4	Stainless steel	1.2	6.15	7.4
	Insulation	PUR 550l	5.5	4.84	26.6	HDPE vacuum panel	3.0	1.10	3.3
						PUR 180l	1.8	4.84	8.7
		Aluminum foil	0.5	11.89	5.9	Aluminum foil	0.5	11.89	5.9
	Evaporator	Aluminum	2.0	11.89	23.8	Aluminum	2.0	11.89	23.8
	Condenser	HDPE	1.0	1.10	1.1	HDPE	1.0	1.10	1.1
	Hot and cold pipe	Cooper	2.0	2.77	5.5	Cooper	2.0	2.77	5.5
	"No Frost" canal	PPE	2.0	2.40	4.8	PPE	2.0	2.40	4.8
	Compressor	Carbon steel	2.3	1.77	4.1		2.7	1.77	4.8
		Aluminum	1.5	11.90	17.9	Aluminum	1.5	11.90	17.9
		Mineral oil	0.5	1.07	0.5	Mineral oil	0.5	1.07	0.5
	Base for the compressor	Galvanized steel	0.5	1.99	1.0	Galvanized steel	0.5	1.99	1.0
	Refrigerant	R290 (propane)	0.7	2.86	2.0	R290 (propane)	0.7	2.86	2.0
	Inside	HDPE	6.5	1.10	7.2	HDPE	6.5	1.10	7.2
	Door seal	PVC	1.0	2.22	2.2	PVC	1.0	2.22	2.2
	Balconies and drawers in the refrigerator	PPE	2.7	2.40	6.5	PPE	2.4	2.40	5.8
	Drawers in the freezer	PP	1.3	1.95	2.5	PP	1.3	1.95	2,5
	Shelfs	Tempered glass	5.0	0.85	4.3	Tempered glass	5.0	0.85	4.3

(*continued*)

Table 1. (*continued*)

		Fridge in a lower energy efficiency class				Fridge in a higher energy efficiency class			
SUM			51.7		214.2		51.1		199.6
Carbon footprint of a single item		740.5				720			
Emission during production [kg CO_2eq]		953.0				917.9			
Usage phase	Electricity consumption [kWh/year]	288				148			
	Kg CO_2eq/kWh	0.836 [28]							
	Annual indirect emission [kg CO_2eq/year]	240.8				123.7			
	Lifetime	10 years				10 years			
Total CO_2 Eq [kg CO_2eq]		2407.7				1237.3			

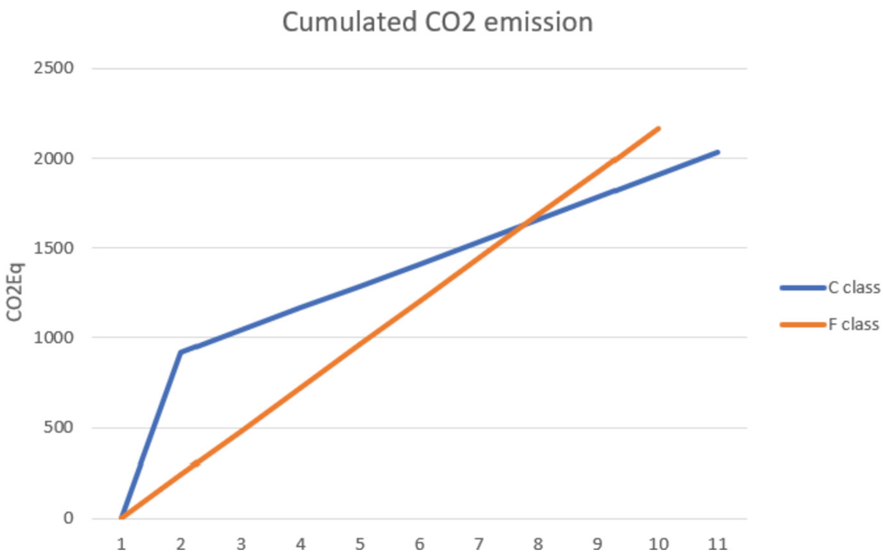


Fig. 3. Comparison of a new refrigerator in energy efficiency class "C" with the use of an existing one in class "F".

5 Conclusions

The main reason for replacing a household appliance is its failure. But energy consumption also ranks high. Using the example of a refrigerator, it has been shown that after 8 years of use, repairing the refrigerator is not profitable, both for environmental and economic reasons. Most of the respondents replace the equipment at a time when its replacement is justified due to the CO_2 balance.

The production of a refrigerator in energy efficiency class "C" is more ecological, mainly due to the lower use of PUR foam, which is a harmful factor, and is visible in the assessment of the carbon footprint for the production process (historically, the carbon footprint was significantly influenced by the abandonment of HCF in the 1990s). In addition, the four years of operation of a refrigerator in energy efficiency class "F" offsets the carbon footprint needed to produce a refrigerator in class "C" – after this period, we start to "save" the natural environment.

If the consumer has a working refrigerator, the difference in energy consumption will make it ecologically viable to replace it after 8 years of use. The relatively long time necessary to balance the environmental impact of replacing a given equipment should aim to shorten it as much as possible. We can get it in three ways:

- by reducing the product carbon footprint - e.g. by reducing the use of natural resources, with particular emphasis on substances that have a negative impact on the climate - e.g. the ban on the use of freon
- by extending the life cycle of a given product - e.g. ensuring the availability of spare parts and enabling repairs in the event of minor failures
- by reducing the energy consumption of the finished product - which is in fact constantly happening for many years due to customer requirements

In many cases, the rapid development of technology and the implementation of new products for sale make it difficult to clearly determine whether the replacement of specific equipment is justified from the point of view of climate protection. A strong share of marketing in the activities of enterprises encourages consumers to make purchases, which are not always environmentally justified, but only constitute greenwashing. The conducted research may constitute an introduction to the further development of the topic: the impact of product development and the implementation of new production standards on the natural environment.

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