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The use of LCA to assess the global ecological competitiveness of selected economies in the area of production of goods

Leszek Kazmierczak-Piwko*, University of Zielona Gora, Podgorna 50B 65-246 Zielona Gora, Poland
Adrianna Dybikowska, University of Zielona Gora, Podgorna 50B 65-246 Zielona Gora, Poland
Grzegorz Ganczewski, COBRO-Packaging Research Institute, Konstancinska 11 02-942 Warsaw, Poland

Abstract

The article addresses the issues of green ecological competitiveness in the global system and its selected aspects. The authors propose using the Life Cycle Assessment (LCA) methodology to assess the global ecological competitiveness of selected economies in their production areas, in terms of the environmental impact of their production processes, determined by the energy mix used in a particular national economy. To compare the environmental impacts of the production of a unified product in selected economies, i.e., France, India, USA and Japan, the ISO standard LCA using the ReCIPe Endpoint v1.13 and IPCC 2013 Global Warming Potential 100 methods and Sima Pro 8.5 software were used. The **LCA** for a 0.5 l plastic bottle was made. Data on the use of electricity for all stages of plastic processing in the bottle were made for energy mixes from France, India, Japan and USA and compared using Ecoinvent 3 database.

Keywords: Global ecological competitiveness, green competitiveness, Life Cycle Assessment (LCA), green economy, ecological competitiveness analysis**.**

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* ADDRESS FOR CORRESPONDENCE: Leszek Kazmierczak-Piwko*, University of Zielona Gora, Podgorna 50B 65-246 Zielona Gora, Poland
E-mail address: l.kazmierczak@wez.uz.zgora.pl

1. Introduction

The requirements of the sustainable development of the global economy and the resulting necessity to look for new instruments to reduce pollution and CO_2 emission generated by the economic systems of individual countries require, in addition to statistically raising the requirements of environmental protection, also the search for market-based instruments that improve the relationship between contemporary economy and the environment. Instruments fostering the implementation of environmental innovations that improve the competitive position of enterprises creating a particular economy. The basis for such actions and the assessment of their effectiveness is conducting comparative analyses of the ecological competitiveness of individual economies, targeted, among others, for measuring the impact on the environment and eco-efficiency of the areas of production of goods in the analysed economic systems. Therefore, this article deals with the issue of evaluating the global competitiveness of selected economies in the area of production using the Life Cycle Assessment (LCA) methodology. The technique allows, among other things, comparing the environmental impact of manufacturing unified products in various economic systems, conditioned by a diversified structure of the energy mix of the countries concerned, which is reflected in the environmental impact characteristics resulting from the production of a particular good in a particular national economy.

2. Theoretical aspects of global economic competitiveness

In 1990, M. Porter from Harvard Business School was the first to put the concept of 'green competitiveness' on theoretical grounds (Cheng, Long, Chen & Li, 2018). Observing international competition and dynamically developing German and Japanese economies, which put forward systematic improvement of environmental protection standards, M. Porter noticed the impact of eco-transformation resulting from these new ecological standards on the emergence of innovation in the area of production of goods, which also improved the competitive position of these economies in a globalised market (Porter, 1991).

In business practice, there is also another market relationship between competitors and an innovation in which the innovative activity of companies is driven by competition on the market, and the search for the so-called 'green innovations', i.e., new, environmentally friendly elements in the development of production and product, involve investments in resources and allow meeting social expectations. It contributes to better use of these resources in the economy, makes supply chains more stable and reduces current operating costs. Such activities also allow creating a positive image of enterprises, because companies engaging in green innovations can get greater social support from external and internal stakeholders and access to valuable resources (Yusuf, Ashari & Razalli, 2018).

As noticed by Liu, Anderson and Cruz (2012) *'The manufacturers, in turn, should understand that eco-friendly production is a new value-adding opportunity in supply chains. If they successfully market the eco-friendly features of the products, they can earn a premium which not only covers the extra cost of eco-friendly productions but also leads to higher total profits'.* In the economic literature, it is pointed out that the transformation of the economy towards improving ecological competitiveness can take place basically on the basis of the adopted two primary strategies. An investment strategy in natural capital and a strategy for increasing efficiency (energy and resource use) related to the functioning of economic sectors based on the transformation of natural capital (Cheng et. al., 2018).

In the case of the efficiency improvement strategy, which mainly concerns the basic sectors of the economy in which, for example, in the process of transformation, natural capital is transformed, the methodology of ecological assessment of competitiveness focused on measuring the effectiveness of natural capital transformation (eco-efficiency) is crucial, determined, among other things, by the level of economic development and the associated intensity of extraction and use of resources and

emissions of pollutants. The issues of measuring the eco-efficiency of the economy in the regional system were dealt with, among other things, by Seppalaa et al. (2008)

At the same time, Meyer and Ahlert (2019) observe that '*The dependency of emissions and extractions of resources from the economic development can only be understood on the basis of models with a deep industry and/or product-specific disaggregation of the economy, which allows identifying the environmentally important consumption, investment and production activities in their relation to the entire economy. So input–output modelling is essential for environmental studies'.* It is worth emphasising that the instrument enabling such modelling and environmental evaluation of economic processes is defined in the standards of ISO and LCA (PKN, 2009).

The usefulness of LCA to assess the global ecological competitiveness of the production of goods in a particular economy, in the context of environmental impact is due, among other things, to the fact that this technique enables the identification of the '*entry*' to the technological processes of material and energy streams as well as enables the identification of emissions generated to all environmental components on the '*exit*' from the analysed production process. What is important, it also allows for an assessment of their impact on the environment and human health and the consumption of resources. Such an assessment in the global comparative perspective is extremely important nowadays, because globalisation itself, as noticed by Zos-Kior, Kuksa, Samoilyk and Storoska (2018) *'globalisation is a major factor affecting the current level of development in most countries of the world'.* In their work, the authors proposed an interesting methodology for assessing the globalisation level of a particular country based on the Integral Index of Globalisation Development. It is worth mentioning here that the assessment of global competitiveness, not only in ecological but full range, is a difficult and very complex process, as multinational and transnational enterprises are increasingly involved in the development of individual national economies. Therefore, the potential conclusions and recommendations for shaping the economic policy resulting from such an assessment obviously encounter practical problems related to regulatory and coordination difficulties at the global level. As observed by Ruggie (2018) *'Globally, there is no central regulator and national laws where multinationals operate may be weak, poorly enforced or simply do not exist'.* Nevertheless, they have value from the point of view of science development and knowledge about development processes in the modern world.

3. Methodology of ecological LCA

The ISO presented the LCA methodology in ISO 14040 14044 standards (Polish version of these standards are: PN-EN ISO 14040:2009 and PN-EN 14044:2009) (PKN, 2009).

According to PN-EN ISO 14044:2009, the ecological LCA is defined as 'collection and assessment of inputs, outputs and potential environmental influences of the product system during its life cycle', and in accordance with the PN-EN ISO 14040:2009 standard, the LCA methodology for the full life cycle of the product is carried out in the following four stages:

♦ goal and scope definition
♦ LCI—Life Cycle Inventory
♦ LCIA—Life Cycle Impact Assessment
♦ interpretation of results.

4. The results of the global ecological competitiveness analysis in the area of production of goods using the LCA methodology with the example of the production of artificial bottles

A LCA was carried out for a 0.5 l plastic bottle intended for the packaging of still water. The bottle consists of the following elements:

♦ PET bottle made by blow moulding from a pre-mould made by injection moulding.
♦ HDPE cap made by injection moulding.
♦ PP label made by extrusion of the foil.

Data for the use of electricity for all stages of plastic processing in the bottle were made for energy mixes from France, India, Japan and USA. The comparison of energy mixes used data from the Ecoinvent 3 database. Two methods were used to assess the life cycle—ReCiPe Endpoint v1.13 and IPCC 2013 Global Warming Potential (GWP) 100. LCA has been performed 'from the cradle to the gate'—that is, from the moment of collecting and processing materials until the ready bottle leaves the factory. Figures 1–4 shows a fragment of the tree of the most important processes for the production of a bottle in France, India, Japan and USA according to the ReCiPe Endpoint v1.13 method. The thickness of the red arrow corresponds to the degree of all environmental influences (according to the Single Score method).
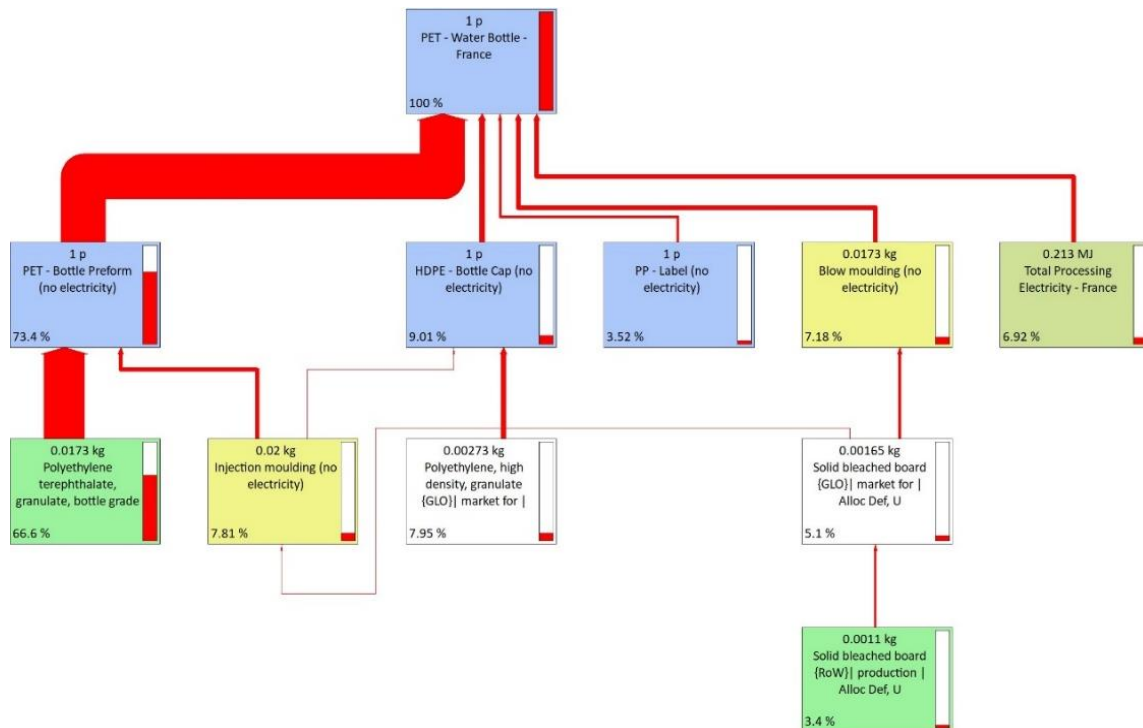

Figure 1. A fragment of the tree of the most important processes for the bottle production in France according to the ReCiPe Endpoint v.1.13 method
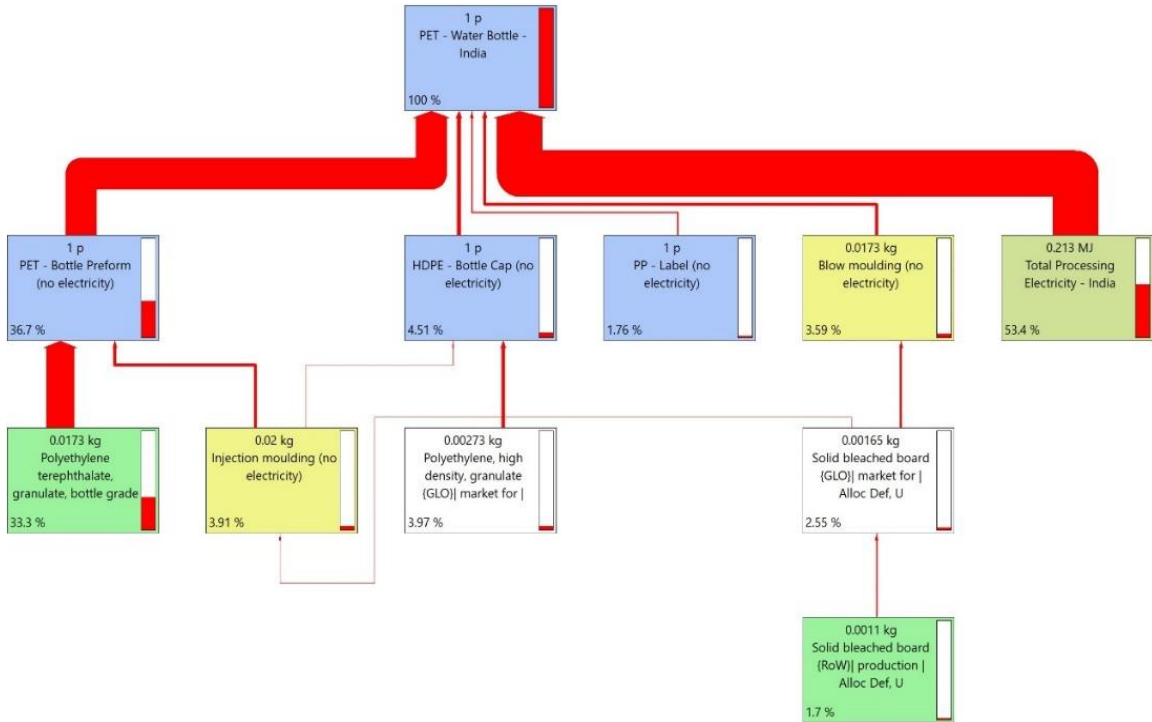
Figure 2. A fragment of the tree of the most important processes for the bottle production in India according to the ReCiPe Endpoint v.1.13 method
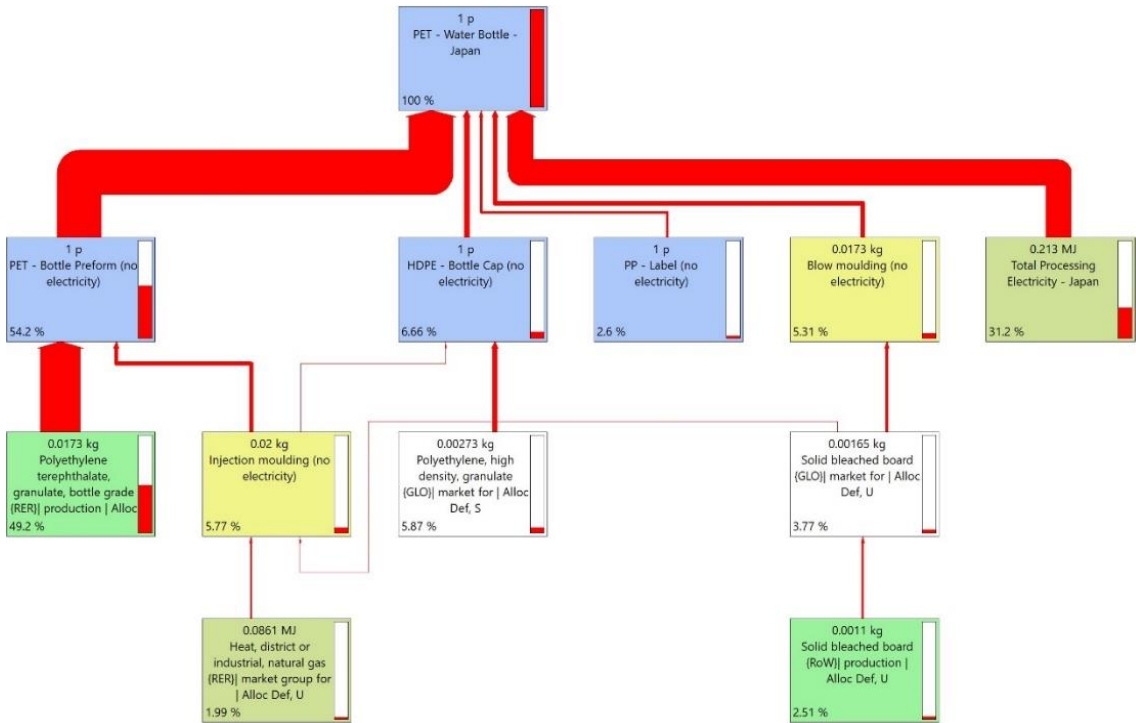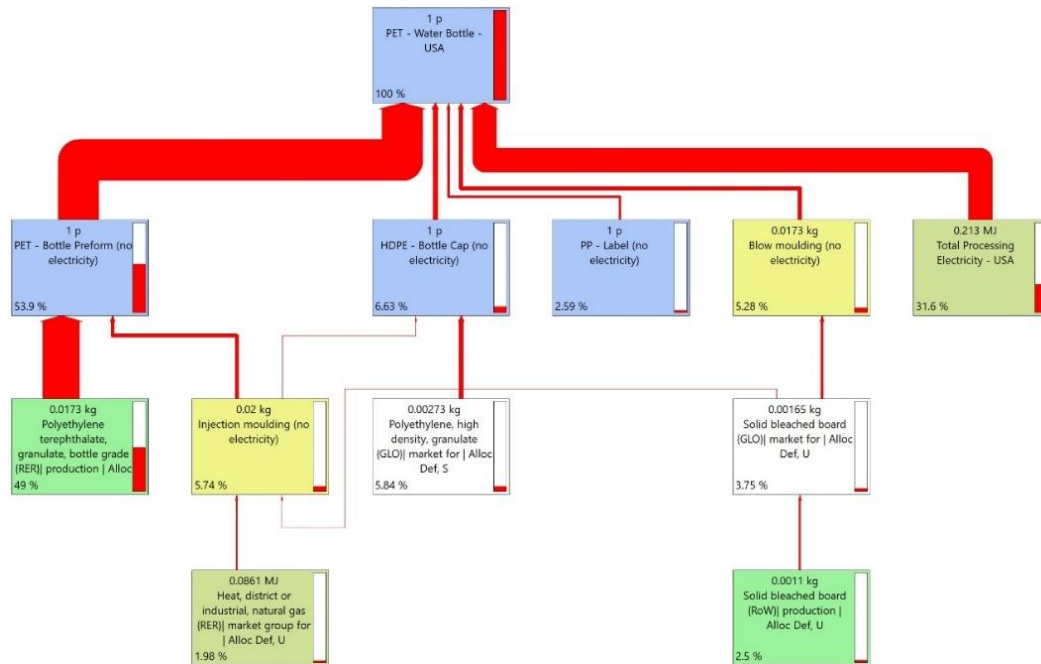

Figure 3. A fragment of the tree of the most important processes for the bottle production in Japan according to the ReCiPe Endpoint v.1.13 method
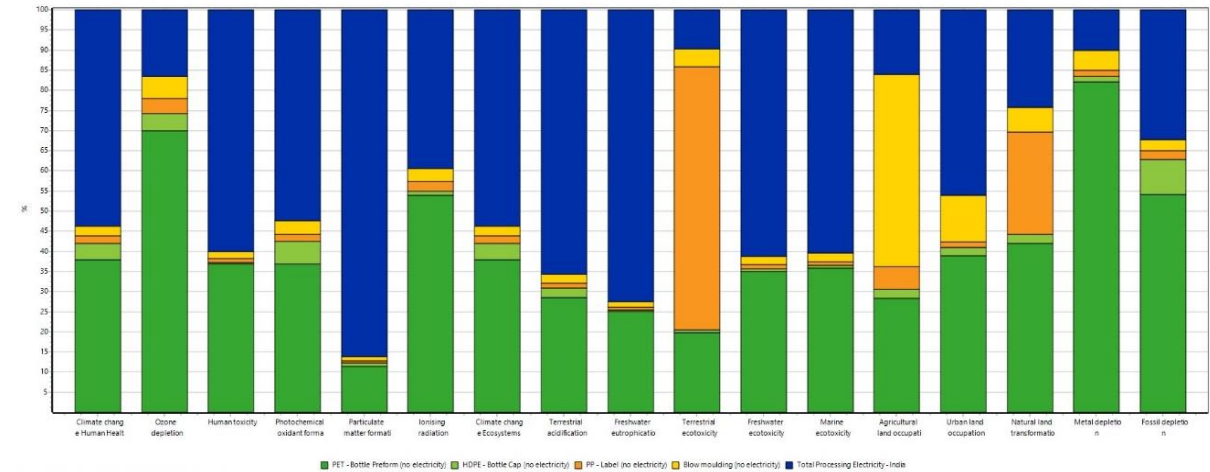
Figure 4. A fragment of the tree of the most important processes for the bottle production in the USA according to the ReCiPe Endpoint v.1.13 method

The influence of the energy mix on bottle production has the following share of all environmental impacts in individual countries: France—6.92%, India—53.4%, Japan—31.2% and USA—31.6%. The very low share of environmental impacts for the energy mix of France is due to the high use of nuclear energy for this country. Atomic energy has much less environmental impact than the energy of carbon-based energy mixes (as in India).
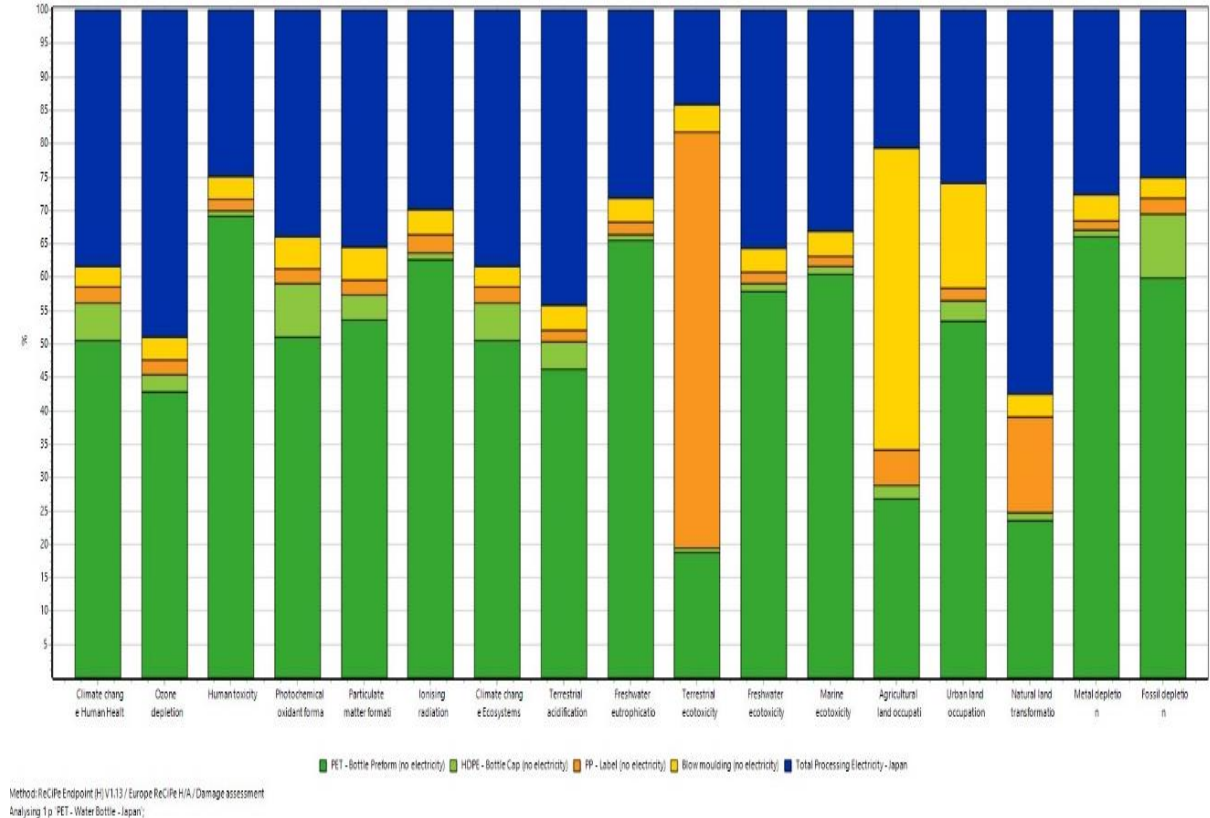
Figures 5–8 present the share of environmental influences of individual bottle elements and electric energy used to form a bottle according to the ReCiPe Endpoint v1.13 method for France, India, Japan and USA.
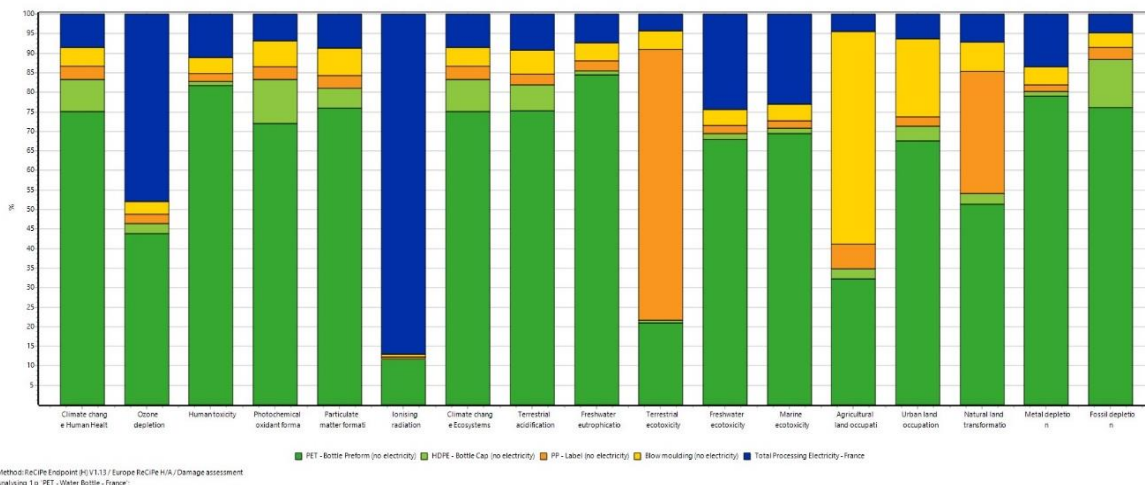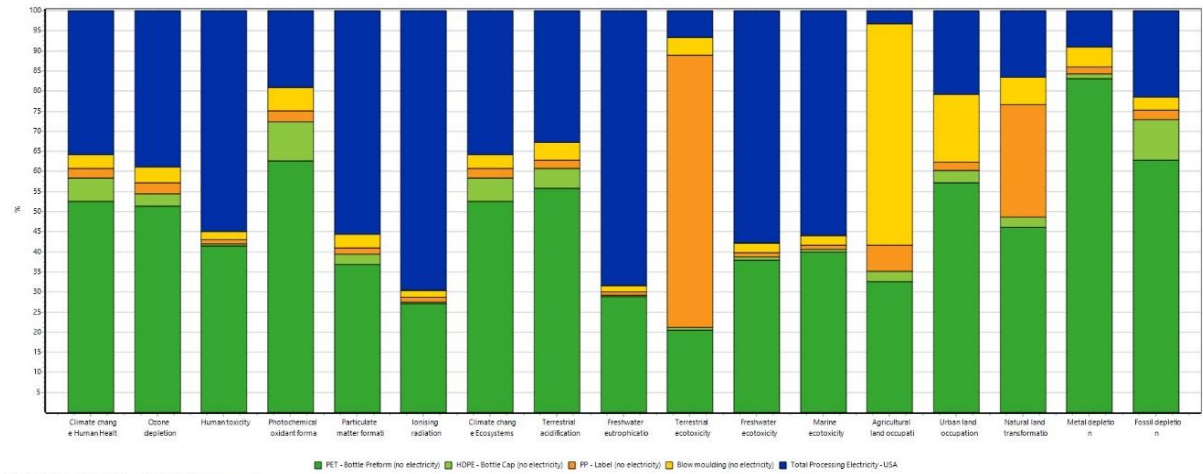

Figure 5. The share of environmental influences on individual elements of the bottle and the use of electricity for France according to the ReCiPe Endpoint v.1.13 method

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Figure 6. The share of environmental influences on individual elements of the bottle and the use of electricity for India according to the ReCiPe Endpoint v.1.13 method


Figure 7. The share of environmental influences on individual elements of the bottle and the use of electricity for Japan according to the ReCiPe Endpoint v.1.13 method

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Figure 8. The share of environmental influences on individual elements of the bottle and the use of electricity for the USA according to the ReCiPe Endpoint v.1.13 method

The charts show that the largest share of electricity in almost all categories of environmental impacts belongs to India—a country that bases its energy management mainly on coal. The main difference in these charts is the category of environmental impact 'Ionising Radiation', which is much higher for the energy mix of France. This is due to the significant use of nuclear energy in this country.

These observations are underlined in Figure 9, which presents the comparison of environmental impacts of bottle production in energy mixes of selected countries according to the ReCiPe Endpoint v1.13method. In this chart, environmental influences were expressed as a percentage and the highest value of damage in a particular category is always presented as 100%.
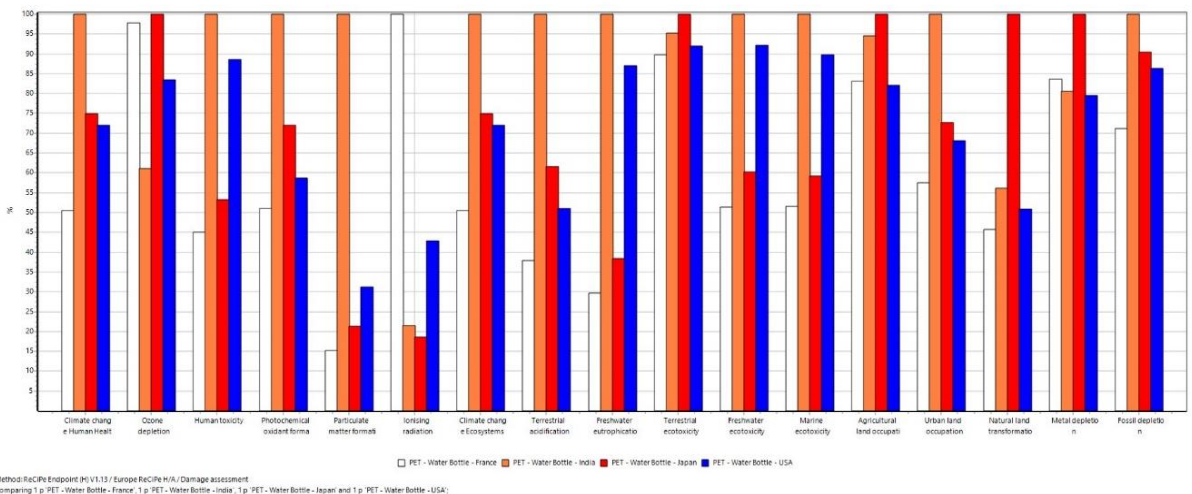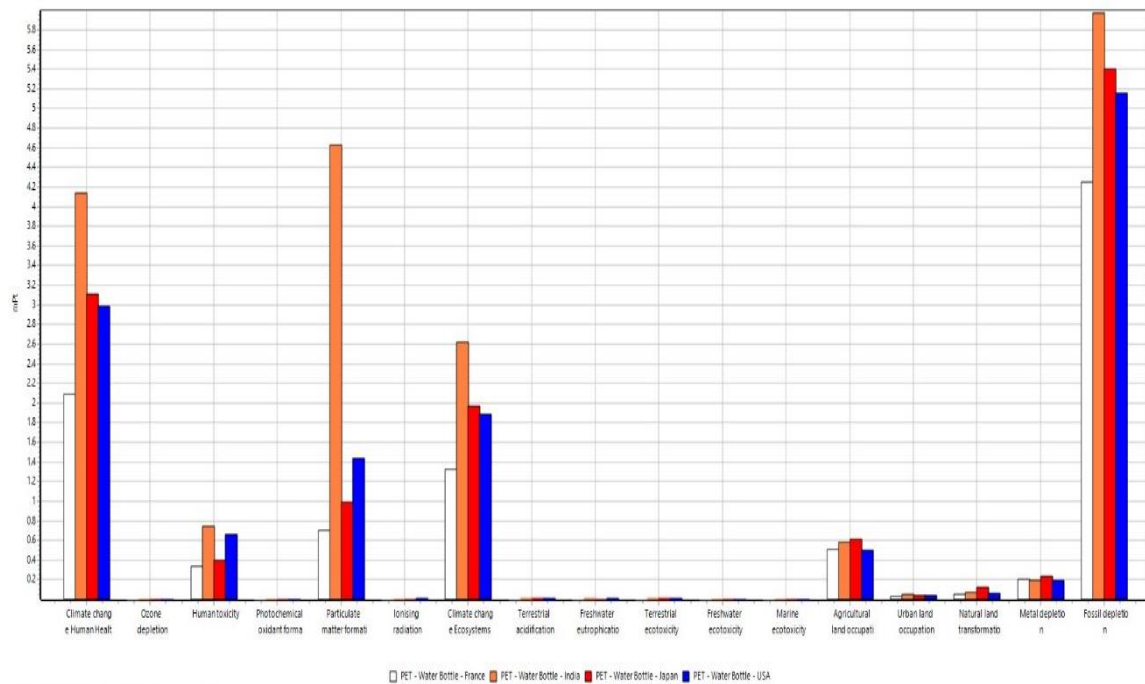

Figure 9. Comparison of the environmental impacts of bottle production in energy mixes of selected countries according to the ReCiPe Endpoint v.1.13method—inflows expressed as a percentage

Figure 10 shows the same comparison using weighing—giving weight to individual environmental influences according to the specification of the ReCiPe Endpoint v.1.13 method. It allows indicating the most important environmental influences for the analysed bottles. The most important categories of environmental impacts for bottles are *Climate Change—Human Health*, *Particulate Matter Formation, Climate Change—Ecosystems and Fossil Depletion*. For all significant impact categories,

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India's energy mix is the most influential, followed by Japan, US and France in the end. According to this method, *Fossil Depletion* is characterised by the greatest impact. A very high environmental impact for India is *Particulate Matter Formation*, which indicates a large amount of harmfulness to human health created by smog generated by the used energy mix.


Method: ReCiPe Endpoint (H) V1.13 / Europe ReCiPe H/A / Weighting
Comparing 1 p 'PET - Water Bottle - France', 1 p 'PET - Water Bottle - India', 1 p 'PET - Water Bottle - Japan' and 1 p 'PET - Water Bottle - USA';

Figure 10. Comparison of the environmental impacts of bottle production in energy mixes of selected countries according to the ReCiPe Endpoint v1.13 method—inflows expressed in points by the weighing method

The ReCiPe Endpoint v1.13 method allows for an additional degree of assessment that accumulates environmental influences into three environmental damages—*Human Health, Ecosystem Quality and Resources*. This allows for easier interpretation and more transparent presentation of results.

Figure 11 shows a comparison of weighted environmental damages in bottle production. In this diagram, India's energy mix has the highest environmental damage, with a significant share of the damage category—*Human Health*.

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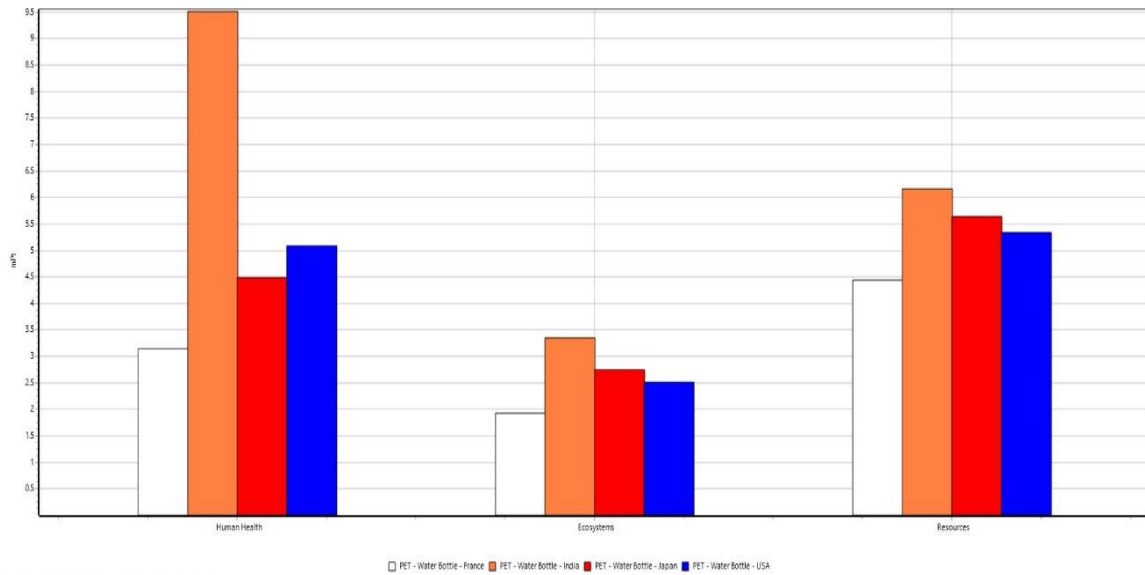
Figure 11. Comparison of three environmental damages in the production of bottles in energy mixes of selected countries according to the ReCiPe Endpoint v.1.13 method—inflows expressed in the form of weighing.

Figure 12 shows the same results according to the ReCiPe Endpoint v1.13 method in the form of Single Score that is—by accumulating particular environmental influences to a single graph. Similarly to the previous charts, the largest environmental impact is the bottle production in India. In this respect, the production of bottles from Japan and USA (despite other energy mixes) is comparable, while the impact of bottle production in France is the smallest.
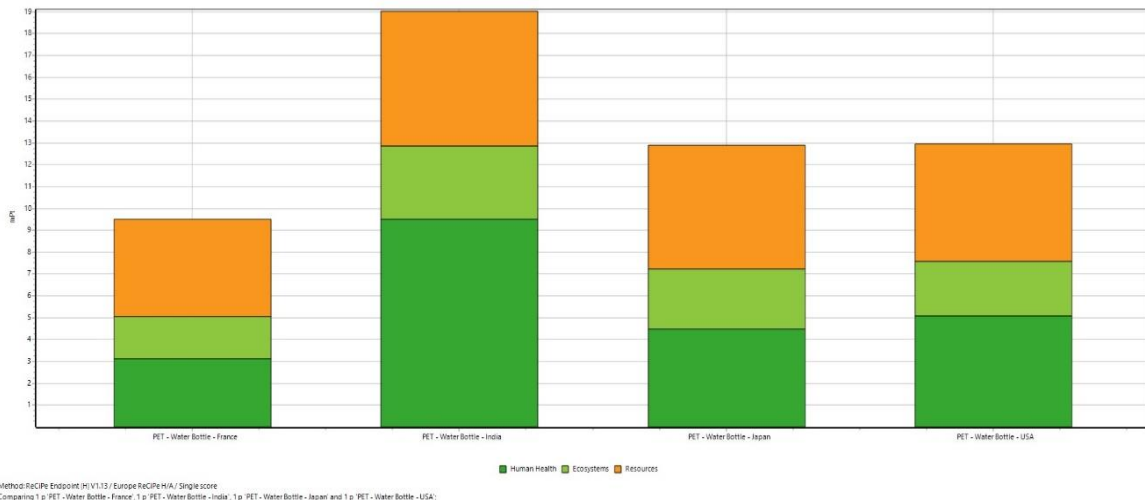

Figure 12. Comparison of three environmental damages in the production of bottles in energy mixes of selected countries according to the ReCiPe Endpoint v.1.13 method—inflows expressed in the form of Single Score

Moreover, IPCC GWP 100 was tested for bottles—this is the Global Warming Potential—this index is used to quantify the impact of particular substances on the greenhouse effect. It compares the amount of heat captured by a specific mass of gas to the amount of heat retained by a similar mass of

carbon dioxide. GWP is converted for a specific time interval, in this case, 100 years. GWP for carbon dioxide is by definition 1.

The results of the Greenhouse Effect Potential expressed in the carbon dioxide emission equivalent and the share of the five most important substances generating this potential for the bottles assessed are presented in Figures 13 and 14.
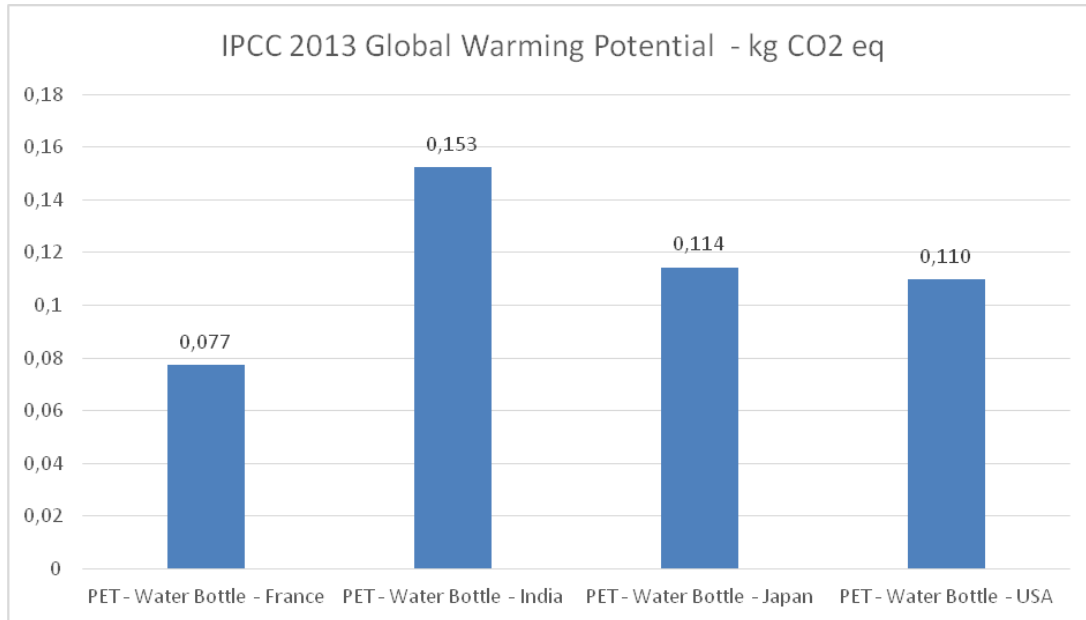
Figure 13. Comparison of the results of the Greenhouse Effect Creation for bottles in energy mixes of individual countries. The production of one PET bottle for water generates 0.077 kg of CO$_2$ emission in France, 0.153 kg of CO$_2$ in India, 0.114 kg of CO$_2$ in Japan and 0.11 kg of CO$_2$ in the USA
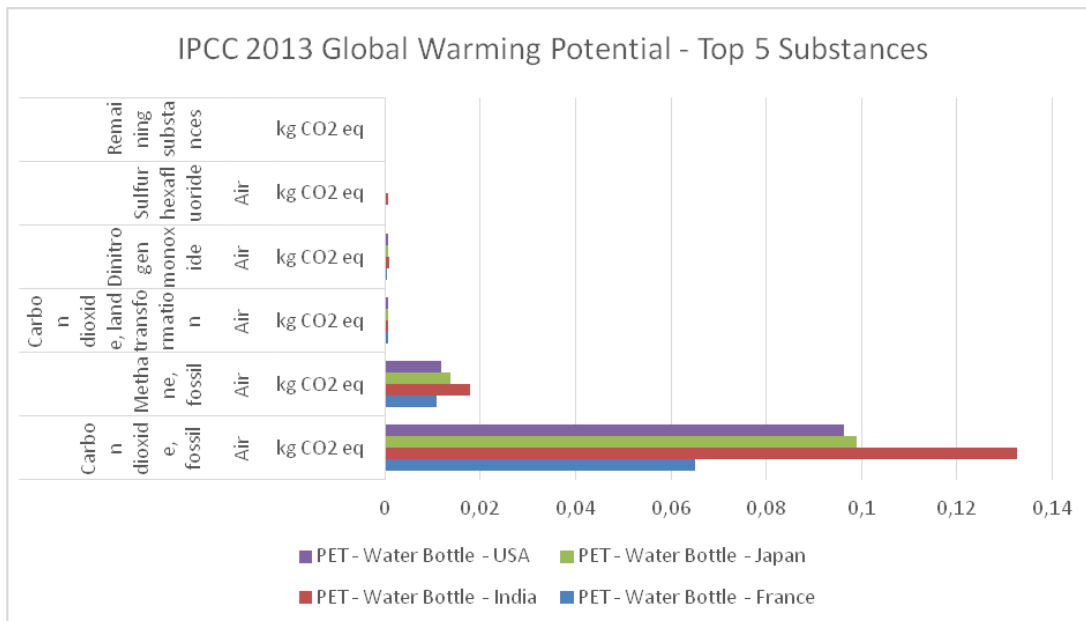
Figure 14. Comparison of the results of the Greenhouse Effect Potential for bottles in energy mixes of individual countries divided into five key substances. The dominant substance is carbon dioxide and then methane.

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5. Conclusions

The aim of the article was to present the issues of ecological competitiveness and its analysis using the LCA methodology. The conducted analysis showed that the LCA methodology specified in the ISO standards may be a useful instrument for a comparative analysis of ecological competitiveness of selected economies in the area of environmental impact associated with the conduct of manufacturing processes. At the same time, it showed how significant influence on diversification of environmental impact characteristics, including potential greenhouse gas emissions, can be used in a particular country, energy mix, used in production processes unified in terms of composition and technology of good production. Being aware of the difficulties of comprehensive comparative assessment of the global competitiveness of traditional national economies resulting, among other things, from the functioning of international and supranational enterprises, affecting, for example, the appropriate allocation of environmental impact in a global system to a particular country, LCA analysis may not be a sufficient instrument for full, comprehensive assessment of green competitiveness of economies and may require application, extending with the analysis of complementary methods, also taking into account other factors. Nevertheless, the results of the comparative LCA analysis can provide interesting, from the researcher's point of view, valuable cognitive information allowing, among other things, for the assessment of the directions of implementation of the assumptions of international agreements regarding the protection of the climate and the environment as well as the pro-ecological development of manufacturing technologies on the international market and methods of eco-designing consumer products.

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