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Water footprint of a 5 kg bag of washed potatoes

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Abstract

Climate change and water scarcity increasingly impact agricultural systems. Therefore, studying food systems in depth through a water footprint perspective and their effects on water resources is necessary. Potatoes are one of the most widely consumed foods globally. This article analyzes the water footprint of a 5 kg bag of washed potatoes using a life cycle assessment (LCA) methodology. A cradle-to-gate model is created, and four environmental impact assessment methods are applied to determine the impacts on water resources. The results obtained are consistent across all four methods, indicating that water consumption in the potato washing stage has the most significant impact. The second highest water consumption occurs during the agricultural cultivation phase. Furthermore, this agricultural phase has the highest impact on other water-related categories, including such as Water Pollutants, Persistent Organic Pollutant (POP) into Water, Heavy Metals into Water, and Radioactive Substances into Water.

Keywords: LCA; Potato; Water footprint

1. Introduction

Potatoes are a widely distributed product worldwide and have high nutritional value. However, the high demand for this product leads to significant production and resource consumption requirements.

On the other hand, the scarcity of water resources is becoming increasingly evident, and it is necessary to study all mass consumption processes and goods in detail from a perspective that considers their impact on this precious resource. Rocha et al. (2020) evaluate the impact on the quantity and quality of available water resources due to the future effects of climate change in the Mediterranean region. They also propose possible strategies to adapt to climate change, primarily focused on the agricultural sector. Dinar et al. (2019) study whether the currently available fresh water will be able to supply the required demand for agricultural crops, taking into account the continuous impact of climate change on this resource. They also emphasize the need to incorporate new technologies that allow us to cope with future population growth and the continued reduction of water resources due to climate change if we want to ensure global food security. These possible global issues are multiplied in the case of developing countries. For example, Nhemachena et al. (2020) highlight that the climate change scenarios suggest reductions of between 15% and 50% in agricultural productivity in the southern African region, with the serious consequences this would have on food insecurity in the region. This makes it necessary to enhance agricultural productivity and invest in sustainable management of water and energy resources in the area.

To achieve sustainable management of resources, it is necessary to study the different production processes involved from the perspective of their impact on water resources. Life Cycle Assessment (LCA) is one of the most commonly used tools to study this type of impact. Following the methodology set by ISO 14040, it is possible to study the environmental impact of any product or process specifically associated with the consumption of water resources and their scarcity.

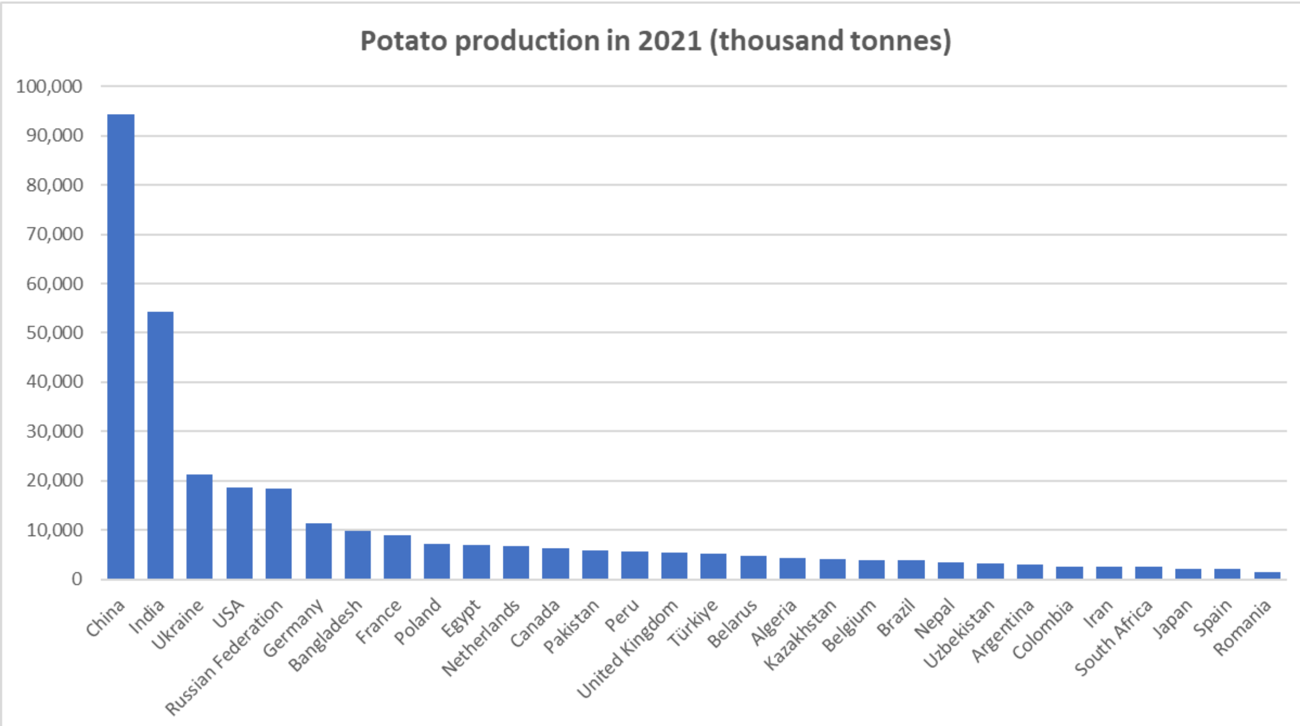

Figure 1. Potato production in 2021

LCA is a quantitative tool that is frequently used to evaluate potential improvements in the environmental performance of a system, process, or product throughout its entire life cycle. LCA has become a highly relevant tool in decision-making related to the field of environmental management (Frankowska et al., 2019; Goffetti et al., 2022; Rusch et al., 2022; Siracusa et al., 2014). An LCA, carried out in accordance with ISO 14040 (Guinée, 2001), enables the identification of the best possible option from an environmental standpoint and provides a basis for evaluating possible improvements introduced into the system under study (Martínez et al., 2009; Martin-Gorriz et al., 2020). Additionally, the ability of LCA to quantify these environmental impacts allows for the identification of potential critical points in the process or product under study and the application of necessary measures to reduce environmental impact in a much more accurate manner (Belussi et al., 2015).

Another notable aspect of LCA is that it allows for the examination of all aspects related to the environment and the possible impacts of products or services, as it considers all phases of the life cycle of each product or process, from the extraction of raw materials to the final waste treatment process at the end of its useful life, including the production process, distribution, or product use phase (Jiménez et al., 2013). In the field of food, LCA has been applied to analyze food products and their production processes. In complex systems like food production, it is particularly important to define system boundaries correctly to obtain accurate and comparable results (Andersson et al., 1994). For example, Noya et al. (2018) used LCA to analyze the environmental impact and water footprint of milk production in northeastern Spain, highlighting that the majority of the water footprint is derived from animal feed and forage cultivation. Similarly, Usva et al. (2023) analyzed the impact on climate change and water resource scarcity in the production process of chickens in Finland, again highlighting that the greatest impact on water resources is due to chicken feed.

This demonstrates the importance of the food chain in the water footprint, and it is becoming increasingly important to reduce its impact, especially considering the present and future effects of climate change. Potatoes are one of the most widely consumed foods worldwide. Figure 1 shows potato production in 2021 by country, with China being the world's largest producer, followed by India, Ukraine, the USA, and Russia. It is important to understand in detail the environmental impacts resulting from this globally relevant food product, especially all aspects related to its impact on water resources. With this in mind, this article proposes an LCA that allows for a detailed study of the water footprint associated with a 5 kg bag of washed potatoes.

2. Materials and Methods

For the inventory used in this LCA, information collected over a period of three years from a potato processing food industry located in La Rioja (Spain) was taken as the primary data source. These primary data collected at the facility allowed for a precise understanding of the production flow and the inputs and outputs derived from the activity being analyzed. For this study, the agricultural phase is clearly separated from the production phase. The agricultural phase covers the entire process of planting, growth, and harvesting of the potatoes. In the production phase, the reception of potatoes, their washing, packaging, and loading of the finished product ready for distribution are considered.

Calculations were carried out by analyzing all phases of the production process using SimaPro software and the Ecoinvent library. The environmental impact assessment methodology used was the Ecological Scarcity 2013 V1.05 methodology. This methodology has five categories that are directly related to water: Water Resources, Water pollutants, Persistent organic pollutant (POP) into water, Heavy metals into water and Radioactive substances into wáter. Additionally, three environmental impact assessment methodologies that provide a unique water scarcity index were evaluated: Hoekstra et al 2012 (Water Scarcity) V1.02 (Hoekstra et al., 2012), Berger et al 2014 (Water Scarcity) V1.00 (Berger et al., 2014), and AWARE V1.00 (Boulay et al., 2018)

Table 1 shows the life cycle inventory of one kilogram of washed potatoes. The phases considered in this inventory are:

- Agricultural stage: Potato cultivation
- Production process stage 0: General consumptions
- Production process stage 1: Reception of potatoes
- Production process stage 2: Washing
- Production process stage 3: Packaging
- Production process stage 4: Loading

2.1. Agricultural stage: Potato cultivation

In this agricultural phase, all information related to the processes of planting, phytosanitary treatments, irrigation, and harvesting of potatoes is considered.

2.2. Production process stage 0: General consumptions

In the production process, a general stage that affects all facilities and includes all general consumptions is considered. Additionally, all consumptions related to the storage chamber of the product that is waiting to be processed or distributed are included within these general consumptions.

2.3. Production process stage 1: Reception of potatoes

In this stage 1 of the production process, all consumptions derived from the reception and preparation of potatoes for subsequent washing and packaging are included.

2.4. Production process stage 2: Washing

In stage 2 of the production process, all consumptions derived from the washing and selection of potatoes are included. The washing process consists of a water tank where the potatoes are cleaned by density difference with respect to other materials. Then, they are passed through an industrial washer to remove any residue that may remain on the potatoes. Finally, they are dried using a roller system and an automatic selection is made using an optical selector.

Table 1. Life cycle inventory per kilogram of washed potatoes

Phase	Item	Quantity	Unit
Agricultural stage	Potatoes	1.18E+00	kg
Production process stage 0	Water	1.63E-03	m3
	Electricity	1.10E-01	kWh
	Cleaning product	2.17E+00	g
	Sprout inhibitor	4.70E-05	kg
	Labor	6.78E-04	hr
Production process stage 1	Pallets	1.08E-03	p
	Crates	2.74E-03	kg
	Yumbos	5.42E-04	kg
	Electricity	1.66E-03	kWh
	Labor	1.35E-04	hr
Production process stage 2	Water	1.55E-01	m3
	Electricity	6.94E-03	kWh
	Labor	1.08E-03	hr
Production process stage 3	Film	1.68E+00	g
	Mesh	3.32E+00	g
	Labels	2.80E+00	g
	Box	6.59E-02	g
	Strapping	7.11E-05	g
	Electricity	6.46E-04	kWh
	Labor	6.59E-04	hr
Production process stage 4	Pallets	1.25E-03	p
	Electricity	1.38E-03	kWh
	Labor	4.16E-04	hr

2.5. Production process stage 3: Packaging

In stage 3 of the production process, all consumptions associated with the packaging process are included. First, the washed potatoes are introduced into the filling hoppers. Then, they are weighed in quantities of 5 kg and bagged. Finally, these 5 kg bags are packaged, palletized, and strapped.

2.6. Production process stage 4: Loading

In stage 4 of the production process, all consumptions associated with the loading of the 5 kg bags into the distribution truck for the finished product are included.

3. Results and Discussion

This article employs 4 environmental impact assessment methodologies that study aspects related to water footprint. One methodology provides results in multiple categories, while the other three provide single value results. The obtained results are presented and analyzed below.

Table 2. Ecological Scarcity 2013

Impact category	Unit	Total	Agricultural stage	Production process stage 0	Production process stage 1	Production process stage 2	Production process stage 3	Production process stage 4
Water resources	*UBP*	*4.86E+02*	*2.32E+02*	*1.04E+00*	*-8.48E-03*	*2.53E+02*	*-1.97E-02*	*6.36E-03*
Energy resources	UBP	1.25E+02	6.70E+01	1.88E+01	1.13E+01	1.89E+01	9.24E+00	2.30E-01
Mineral resources	UBP	8.90E+01	6.83E+01	3.19E+00	1.94E+00	1.37E+01	1.83E+00	3.19E-02
Land use	UBP	6.58E+02	6.34E+02	1.36E+00	1.99E+01	1.92E+00	1.40E+00	1.54E-02
Global warming	UBP	8.54E+02	5.02E+02	1.27E+02	3.87E+01	1.42E+02	4.32E+01	1.50E+00
Ozone layer depletion	UBP	3.08E+00	2.31E+00	3.68E-01	4.82E-02	3.18E-01	2.89E-02	3.81E-03
Main air pollutants and PM	UBP	7.43E+02	5.02E+02	8.43E+01	3.11E+01	9.82E+01	2.63E+01	9.88E-01
Carcinogenic substances into air	UBP	1.34E+02	7.03E+01	6.48E+00	9.02E+00	4.56E+01	2.55E+00	7.23E-02
Heavy metals into air	UBP	1.65E+02	9.69E+01	1.78E+01	3.82E+00	4.44E+01	1.93E+00	1.99E-01
Water pollutants	*UBP*	*2.69E+03*	*2.68E+03*	*3.89E+00*	*2.51E+00*	*3.93E+00*	*1.50E+00*	*3.04E-02*
POP into water	*UBP*	*3.84E+01*	*3.40E+01*	*2.04E+00*	*7.31E-01*	*1.39E+00*	*2.67E-01*	*1.63E-02*
Heavy metals into water	*UBP*	*2.60E+02*	*2.07E+02*	*4.33E+00*	*2.37E+00*	*4.37E+01*	*2.01E+00*	*4.80E-02*
Pesticides into soil	UBP	8.67E+02	8.67E+02	2.55E-02	2.40E-02	3.99E-02	5.65E-02	2.92E-04
Heavy metals into soil	UBP	6.92E+02	6.87E+02	2.76E+00	7.08E-01	1.23E+00	6.51E-01	3.39E-02
Radioactive substances into air	UBP	2.35E-05	4.73E-06	9.37E-06	5.02E-07	8.29E-06	5.00E-07	1.16E-07
Radioactive substances into water	*UBP*	*1.04E+00*	*2.03E-01*	*3.91E-01*	*2.03E-02*	*3.90E-01*	*2.97E-02*	*4.66E-03*
Noise	UBP	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non radioactive waste to deposit	UBP	4.51E+00	1.84E+00	2.78E-01	2.19E-01	1.54E+00	6.32E-01	3.10E-03
Radioactive waste to deposit	UBP	9.22E+01	1.81E+01	3.41E+01	1.83E+00	3.51E+01	2.67E+00	4.19E-01

Table 3. Single Value Water Scarcity Methodologies

LCIA	Impact category	Unit	Total	Agricultural stage	Production process stage 0	Production process stage 1	Production process stage 2	Production process stage 3	Production process stage 4
AWARE	Water use	m3	2.16E+01	4.44E+00	1.16E+00	2.85E-02	1.60E+01	3.97E-02	9.92E-04
Berger et al 2014	WDI	m3	4.59E-01	1.55E-02	1.01E-03	3.86E-04	4.42E-01	5.31E-04	1.13E-05
Hoekstra et al 2012	WSI	m3	3.80E-01	-8.98E-02	1.49E-02	8.34E-04	4.53E-01	1.12E-03	2.25E-05

3.1. Ecological Scarcity 2013 methodology

In this environmental impact assessment methodology, there are 5 categories directly related to water: Water Resources, Water Pollutants, Persistent Organic Pollutant (POP) into Water, Heavy Metals into Water, and Radioactive Substances into Water (see Table 2).

Regarding water resource consumption, reflected in the Water Resources category, it can be seen that the stage with the highest impact is associated with the washing process in stage 2 of the production process. In this stage, water is a significant element for washing potatoes. Another important stage in water resource consumption is the agricultural phase, mainly due to crop irrigation during the growth phase.

In the other relevant impact categories, from the perspective of water resources, the agricultural phase has the highest impact. In general, in this agricultural phase, there is a significant contribution of pesticides and fertilizers, as well as the use of heavy machinery for fieldwork.

3.2. Single Value Water Scarcity Methodologies

In this case, three single-value assessment methodologies directly related to water footprint have been employed: AWARE, Berger et al 2014, and Hoekstra et al 2012 (see Table 3).

In all three assessment methodologies, it is indicated that the stage with the highest impact is stage 2 of the production process, coinciding with the results shown in the water resource consumption category of the Ecological Scarcity 2013 methodology.

The only discrepancy among these three impact assessment methodologies is that the Hoekstra et al 2012 methodology does not present the agricultural phase as the second stage with the highest water footprint, but presents negative values for water resource consumption. This value is not in line with the others and may be due to an overvaluation of the percentage of water contained in the potato once it is cultivated.

4. Conclusions

In this article, a life cycle assessment (LCA) has been carried out from cradle to gate for a 5 kg bag of washed potatoes. This LCA model has been used to calculate the water footprint of this product under 4 environmental impact assessment methodologies.

The results obtained coincide in all 4 employed methodologies, indicating that water resource consumption in the potato washing stage is the most important. The second stage with the highest water consumption is the agricultural phase of potato cultivation.

Furthermore, this agricultural phase has the highest impact in other categories directly related to water, such as Water Pollutants, Persistent Organic Pollutant (POP) into Water, Heavy Metals into Water, and Radioactive Substances into Water.

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