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Linking Water Footprint with the Sustainable Development Goals: a Step-by-Step Method Description and Case Study

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Abstract

This paper calculated the water footprint (WF) of chilled chicken meat processing under alternative scenarios, including the contribution analysis to the Sustainable Development Goals (SDG). Volumetric WF was calculated according to the WF Network approach. The contribution of the system to the SDGs was analyzed using a qualitative screening approach. The results showed a WF of 136.1 liters for processing 1 kg of chilled chicken meat, with 0.7 liters from blue water and 135.4 liters from grey water. The wastewater treatment processes accounted for 99.5% of the total WF. According to scenarios analysis, to reduce the total WF of chilled chicken, it is necessary to invest in wastewater treatment technologies. The SDG analysis revealed potential positive contributions of the system to SDGs 2, 3, 6, 12, and 14 if the improvement scenarios are put in practice. The WF-SDG analysis was beneficial to evaluate the role of chicken meat processing in the search for SDGs, and to evaluate how the improvement opportunities can influence the system's relationship to the SDG. The methodology for connecting the SDGs to environmental metrics can be replicated for any type organizations, enabling the integration of the SDGs in production chains. Connecting environmental metrics to the SDGs can indicate directions for production systems seeking sustainability improvements. Thus, it becomes beneficial for society's search for 17 SDGs. There are few studies concerning WF and the SDGs, especially regarding industrialized products. Thus, this paper can contribute to this gap.

1 Introduction

Water is considered to be the fundamental basis for human health and economic development [1]. However, only 2.5% of the water in the world is fresh water, and only 1% is available for consumption and use in productive activities [2].

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Thus, one of the greatest human challenges is to manage natural resources while producing food to meet the increasing demands of human population [3]. According to the United Nations [4] outlook, by the year 2050, the world population will reach the 9.7 billion mark. This population increase will demand more global food consumption and competition among water users.

In the international food market, Brazil stands out as the fourth-largest producer of chicken meat in the world, surpassing the mark of 13.5 million tons in 2019 [5]. Additionally, in 2020, the per capita consumption of this product in the country was approximately 45 kilograms per inhabitant [6]. As a consequence, the Brazilian food industry stands out in terms of water demand and wastewater generation. The industrial sector is the third largest water consumer (9.7%), a value higher than what is consumed, such as in urban supply (9%) [7]. Within the manufacturing industry sectors, 55.8% of water is used by food industry [7], and much of this water is consumed, i.e., not returning to the same water body from which it came.

The term "water footprint" (WF) derives from the concept of "virtual water" which refers to the total amount of water directly and indirectly required to manufacture and consume a product [8]. This indicator has an analogy with the concept of Ecological Footprint and has been used by different sectors of society [9]. According to Hoekstra et al [10], the WF is divided in green, blue, and grey water. Blue water refers to the surface water and groundwater available in a watershed; green water refers to rainwater available in soil for plants; and grey water refers to the amount of water needed to dilute pollution, assuring water quality standards.

The WF is a multidimensional indicator, which show the volume of water use, where the WF is located, what source of water is used, and when the water is used [10]. Thus, the water footprint indicator focuses on water management from a broad view of the different types of water (i.e., blue, green, and grey) needed to produce a product and to dilute the pollutants emitted during the production stages. This indicator was employed by several studies concerning livestock production in recent years [11].

The food production and water scarcity are prominent topics in current scientific research, as they directly affect human survival and sustainable development as a whole [12]. However, many previous WF studies focused on crop and livestock production [13]. Regarding animal based products, many studies focused on beef and pork production [14] and in the slaughtering processes of these animals [15].

In the Brazilian context, WF studies have focused on cattle dairy products, such as milk, cheese, yogurt, and butter [16], crop management [17], and beef cattle production systems [18]. Furthermore, Arbaiza and Quispe [19] calculated the WF of Peruvian broiled chicken, but no previous study has analyzed the WF of industrialized chilled chicken meat so far.

The WF assessments assist various stakeholders in public policy, planning, and production, contributing to driving initiatives to achieve the SDGs, especially improvements concerning the sustainable use of water resources [20]. The water footprint toolbox, developed by the GRoW project [21], related the use and quality of water to impacts on natural resources, ecosystems, and human health. This relationship was identified especially between WF and SDG 2 (zero hunger), 3 (good health and well-being), 6 (clean water and sanitation), 12 (responsible consumption and production), and 14 (life below water). However, more studies in the topic of WF and the SDGs are desired to fill the existing gap regarding WF of industrialized products and its contributions to the achievement of the SDGs, for example.

In this regard, and given the importance of the poultry sector to the world market, this study evaluated the WF of chilled chicken meat processing, applying the volumetric method proposed by the WFN. Furthermore, it investigated the WF contributions within the SDGs agenda to support future strategies based on sustainable management in production systems

2 Methodology

This study followed the WF manual developed by the Water Footprint Network (WFN) [10] and the approach proposed by Weidema et al [22] to analyze the contribution of WF to the SDGs. Weidema et al [22] proposed a recent method of linking the impacts of a production system for a given impact category with the SDG indicators. Thus, this approach enables the integration of the SDGs in production systems, as shown throughout this work.

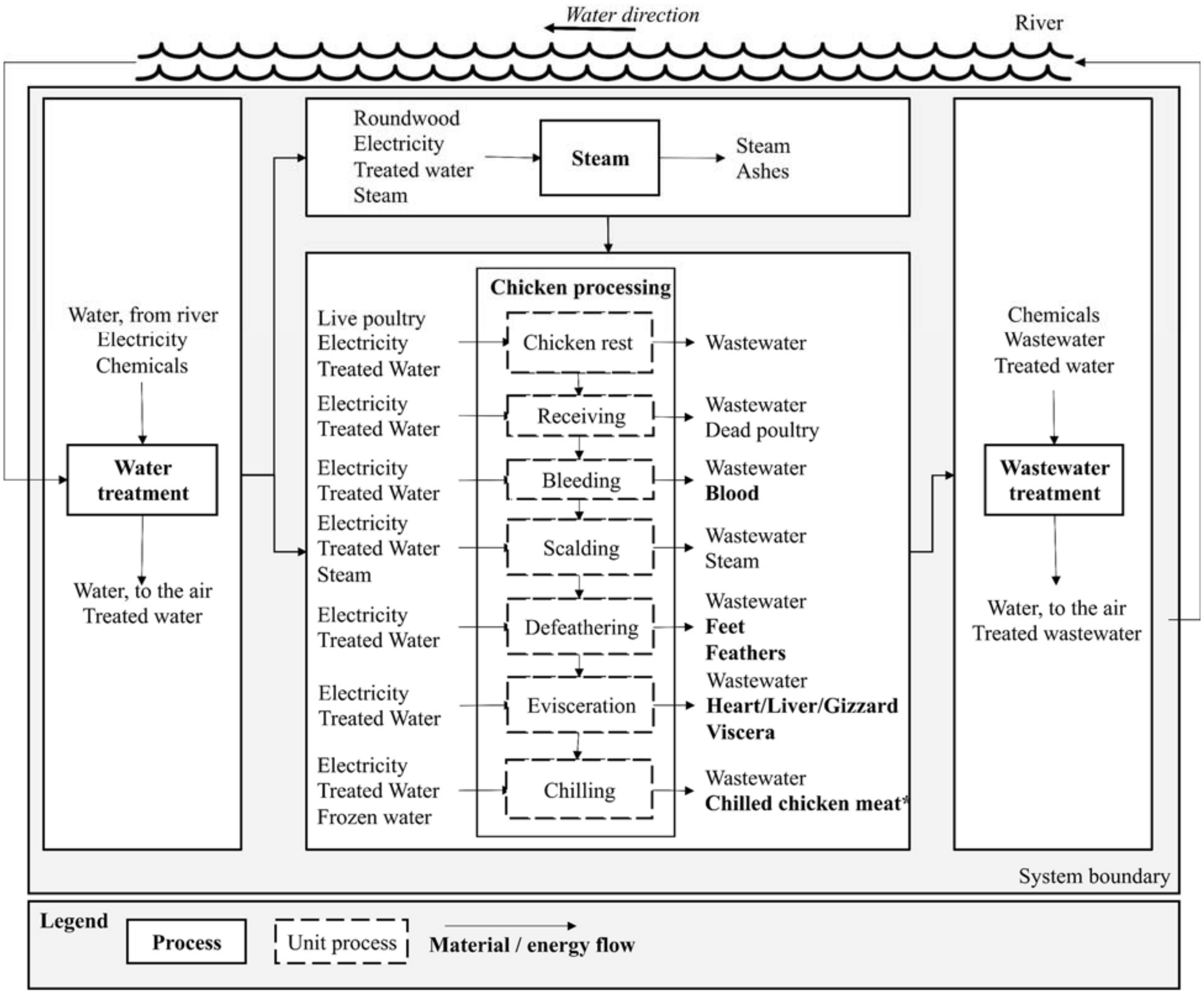

Fig. 1 System boundary and flow quantification per kg of chilled chicken meat.

2.1 System description and inventory

Following the WFN guide [10], the scope of this work was gate-to-gate, focusing on the chilled chicken manufacturing system. The functional unit (FU) was 1 kg of chilled chicken meat. The product system encompassed the main seven stages of chicken processing and three auxiliary processes: water treatment, steam generation, and wastewater treatment (Fig.1).

This study was based on a Brazilian company located in the state of Goiás, Brazil, within the Tocantins-Araguaia watershed. This company produces on average 727.026 kg of chilled chicken meat per day and seven coproducts: blood, feathers, feet, heart, liver, gizzard, and viscera. The company had hydrometers that provided water volumes per production stage, and the input/output inventory data were collected through interviews with the managers of the company during one year of data collection and treatment.

All water used coming from a local river (blue water). Water was treated and used to produce steam, an input in scalding process, and chicken meat, generating wastewater that was treated through physical-chemical and biological processes (two anaerobic and two optional tanks). All water used and the treated wastewater were taken from and returned to the same river. The water catchment point was downstream of the launch point with water meeting the Brazilian quality parameters.

At the resting stage, the chickens arriving in trucks were unloaded and rested in a room. Employees placed

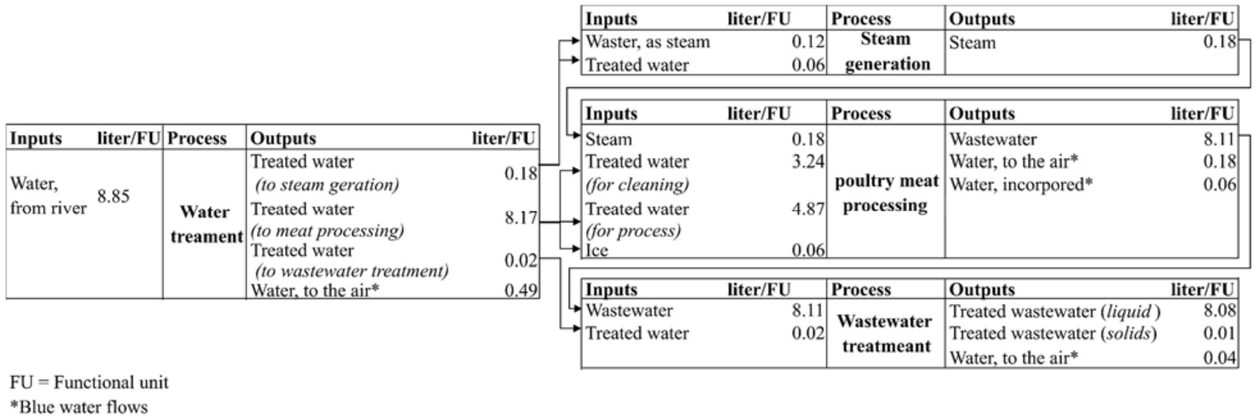

Fig. 2 Balance of water flows.

the live chicken on treadmills at the receiving stage. From there, chickens were moved to the innermost platforms. Numbness and slaughtering took place during the bleeding stage. The blood obtained was sold to animal feed companies.

Subsequently, chickens were submerged in two tanks of steam-heated water (54°C to 64°C) to loosen their feathers (scalding process). They were then sent to the defeathering process and the feathers were sold to flour producers. Next, chickens were eviscerated during the internal cleaning. The giblets (heart, liver, and gizzard) were coproducts of this stage and were marketed separately. Lastly, the carcasses went through the chilling stage. They arrived with an average temperature of 40°C - 45°C and left with a temperature lower than 7 °C, after passing through cold-water tanks.

2.2 Water footprint

The WF of chilled chicken meat was calculated considering two steps: 1) total WF (blue plus grey WF) of the industrial processes and 2) product WF calculation.

2.2.1 The water footprint of chicken processing

The blue WF of chicken processing was calculated according to Equation 1 based on Hoekstra et al [10].

$$\text{Blue WF}_{\text{proc}}\left[\frac{m^2}{kg}\right] = \frac{BW_{\text{evaporation}}\left(\frac{\text{liter}}{\text{day}}\right) + BW_{\text{incorporation}}\left(\frac{\text{liter}}{\text{day}}\right) + BW_{\text{Lost Return Flow}}\left(\frac{\text{liter}}{\text{day}}\right)}{\text{productivity}\left(\frac{\text{kg}}{\text{day}}\right)} \tag{1}$$

In Eq. (1), $BW_{\text{evaporation}}$ refers to the volume of blue water that evaporated in the process; $BW_{\text{incorporation}}$ refers to the entire amount of blue water that was incorporated into chilled chicken; $BW_{\text{Lost Return Flow}}$ represents the volume of blue water that was not available in the same river basin for reuse in the same collecting period (water launched into another hydrographic basin, or into the ocean, or at a time after collection), and productivity refers to the amount of chilled chicken meat (kg) produced during one day.

The system presented blue water evaporation in water treatment, scalding processes, in which the steam was used to heat water, and in wastewater treatment. This type of lost water was accounted as $BW_{\text{evaporation}}$ in Equation 1. The system also exhibited water incorporation into the product ($BW_{\text{incorporation}}$), which occurred during the chilling process. The other blue water inputs left the system as treated wastewater (Fig.1). The system maintains a continuous flow of water collection and discharge, and almost all the water collected returns to the same water body. Thus, there was no water of lost return in this processing scheme. The quantification of each water flow is given in Fig.2.

Grey water was calculated using Equation 2 based on Hoekstra et al [10]. This equation was specific to a point source of water pollution and consequently fitted the analyzed process.

Table 1 Wastewater parameters before and after the treatment.

Parameter	Collected water* (mg/L)	Raw wastewater (mg/L)	Treated wastewater (mg/L)
BOD – Biochemical Oxygen Demand	5.00	4,603.54	76.50
COD – Chemical Oxygen Demand	Not measured	9,069.65	245.64
Total solids	500.00	2,513.33	640.00
Oils and Greases	Virtually absent	2,355.00	< 10.00
Dissolved oxygen	≥ 5	2.80	5.32
Dissolved iron	0.30	0.29	< 0.10
Phosphorus (total)	0.05	16.85	1.00
Ammoniacal Nitrogen	2.00	67.20	18.48

**Parameters obtained from CONAMA Resolution 357 [23]*

$$\text{Grey WF}_{\text{proc}}[\frac{\text{liter}}{\text{kg}}] = \frac{(\frac{(\text{Efl}(\frac{\text{liter}}{\text{day}})\times C_{\text{Efl}}(\frac{\text{mg}}{\text{liter}}))-(\text{Cap}(\frac{\text{liter}}{\text{day}})\times C_{\text{catch}}(\frac{\text{mg}}{\text{liter}}))}{C_{\max}(\frac{\text{mg}}{\text{liter}})-C_{\text{nat}}(\frac{\text{mg}}{\text{liter}})})}{\text{productivity}(\frac{\text{kg}}{\text{day}})}. \quad (2)$$

In Eq. (2), Efl means the wastewater volume at the end of the chilled chicken processing (see Fig.2); C_{Eflu} means the pollutant concentration of wastewater; Cap means the volume of water collected at the beginning of the processes (see Fig.2); C_{catch} means the concentration of pollutants in the collected water; $C_{\max}$ means the maximum accepted concentration of pollutants; and C_{nat} means the concentration of natural pollutants in the receiving water body.

The untreated and treated wastewater parameters were provided by the company, while the collected water parameters were obtained from Conama Resolution 357 [23] (Table 1).

The concentration of pollutants in the wastewater considered the parameters after the treatment process. The element phosphorus was the pollutant used in this paper to estimate the grey WF (C_{Eflu}). This element is highly presented in animal blood and has affected freshwater eutrophication processes [24]. The river that supplies the water falls under Class II of the Conama Resolution 357. In this class, the phosphorus concentration limit is 0.05 mg per liter for lotic environments, which was the value adopted as the maximum phosphorus concentration in Equation 2 ($C_{\max}$).

Natural concentration corresponds to the phosphorous concentration without any human intervention in the watershed. According to Hoekstra et al [10], when the natural concentration is not known, it is acceptable to consider it null. Moreover, water quality monitoring at six points in the river that supplies the company indicated that the concentration of phosphorous was below detectable limit in 2016 [25]. Thus, the natural concentration of phosphorous was considered null (C_{nat}). The concentration of pollutants in the collected water (C_{catch}) was assumed as 0.05 mg per liter (Table 1), i.e., the default concentration for Class II river, available in the Conama Resolution 357 [23].

The blue WF calculation was analyzed separately for each processing unit in Fig.1, while the grey WF was only analyzed for the wastewater treatment process. The final WF was calculated as the sum of the blue and grey WFs of all industrial processes in the system boundary.

2.2.2 The water footprint of chilled chicken meat

The analyzed system was multifunctional producing eight different products from chicken (Fig.1). In that way, allocation procedure was necessary to obtain the WF of chilled chicken meat. Allocation was applied for blue and grey WF of all chicken processing steps. This study adopted the economic allocation criteria in the baseline scenario because Hoekstra et al [10] recommended it as the most meaningful approach. In this approach, the contribution of each product in the total system's WF is proportional to the market value generated by the respective product of interest concerning the total market value generated by the system (in R$/day). On the other hand, in mass allocation the proportion is based on the product's weight. The market price, the raw mass,

Table 2 Economic and mass allocation of chicken-based products.

Product	Market value (R$/kg)	Weight (kg/day)	Mass allocation (%)	Economic allocation (%)
Chilled chicken meat	4.20	727,026	76.59%	88.61%
Blood	0.18	22,710	3.35%	6.91%
Feet	7.49	31,794	1.09%	1.31%
Feathers	0.18	59,045	0.33%	1.26%
Viscera	0.22	80,847	1.50%	0.97%
Heart	13.81	3,133	8.52%	0.52%
Liver	2.34	14,271	6.22%	0.31%
Gizzard	4.35	10,393	2.39%	0.12%
Total	32.77	949,218	100%	100%

and the percentages for allocation of each product are presented in Table 2. The market values are expressed in Brazilian currency (R$).

The market value of the by-products showed that the chicken heart and feet have important markets in Brazil. However, the chilled chicken meat represented the highest mass of products in the system and therefore presents the highest allocation in both mass and economic approaches.

2.3 Scenario analysis

A sensitivity analysis was performed to better understand the product WF results and to investigate potential improvements in the system. Three different scenarios were analyzed. Scenarios 1 and 2 assessed the influence of methodological choices. The economic allocation was used in the base scenario, as recommended by Hoekstra et al [10]; however, a mass allocation was also a viable option and was considered as Scenario 1.

Hoekstra et al [10] also left the pollutant selection as a decision for the WF practitioner. Ammoniacal nitrogen was found in the analyzed effluent (Table 1), and it may cause water eutrophication, and can be toxic to many fish species [26]. Thus, ammoniacal nitrogen instead of total phosphorous was used to calculate the grey WF, as Scenario 2.

Scenario 3 assessed an opportunity to reduce the grey WF. Wastewater treatment showed 94% phosphorus removal efficiency, and aluminum sulfate was used as a coagulant in the current company. However, Nardi et al [27] and Schatzmann [28] identified levels of phosphorus removal of 95% using ferric sulfate as coagulant, and 99% using cationic polymers as flocculant, respectively. Both cited studies were developed for Brazilian poultry industry effluents management.

Summarizing, three scenarios were compared to the base scenario:

Scenario 1: A mass allocation procedure (Table 2) was used instead of the economic one.

Scenario 2: The ammoniacal nitrogen pollutant was used instead of phosphorus for grey WF calculation (equation 2). The treated wastewater concentration of ammoniacal nitrogen (Table 1) was adopted as the effluent concentration (18.48 mg/liter) (C_{Eflu}). The natural concentration of this pollutant was also assumed to be zero (C_{nat}). The catchment concentration (C_{catch}) and the maximum concentration ($C_{\max}$) were provided by Conama Resolution 357 [23], which were equal to 2.0 mg per liter for the evaluated river.

Scenario 3: The grey WF was calculated for phosphorus considering 95% efficiency removal using ferric sulfate as coagulant [28], and 99% using cationic polymers as flocculants [27]. Thus, the concentration of phosphorous in wastewater (C_{Eflu}) was changed from 1 mg/L to 0.84 mg/L and 0.17 mg/L, respectively.

It is important to mention that, except for the aforementioned changes, these alternative scenarios were kept with the same parameters of the base scenario.

Table 3 The score scale used for comparing the blue and grey WF results of products. Source: Weidema et al [22], adapted for the *Water Footprint* context.

Score	Description
+2	The *water footprint* is a lot lower than the benchmark (>10%)
+1	The *water footprint* is significantly lower than the benchmark (5 to 10%)
0	There is no significant difference in *water footprint*
-1	The *water footprint* is significantly higher than the benchmark (5 to 10%)
-2	The *water footprint* is a lot higher than the benchmark (> 10%)

2.4 Linking the sustainable development goals (SDGs) to water footprint (WF)

As a measure towards the 2030 Agenda [29], the contribution of the WF of chilled chicken meat to the SDGs was investigated. This analysis was performed following the qualitative screening approach proposed by Weidema et al [22].

The Weidema et al [22] approach was developed to evaluate the relationship of the results of the Life Cycle Assessments with the SDGs, and did not cover the blue and grey WF indicators. Thus, the analyses employed in this work have been adapted to be used in the WF results, considering 4 steps: 1) identification of affected SDGs; 2) benchmark selection; 3) analysis of WF contribution to SDG; 4) interpretation. In this way, the SDGs potentially affected by blue and grey WF were identified and related to SDG indicators individually (step 1). The SDG analyzed were number 2 (zero hunger), 3 (good health and well-being), 6 (water availability), 12 (water quality), and 14 (water use efficiency). This selection was based on the "water footprint Toolbox", developed by the GRoW Project [21], followed by a thorough analysis of Brazilian indicators of each selected SDG, as recommended by Weidema et al [22] and Wulf et al [30].

Thereafter, a benchmark was chosen for analyzing the relative contribution of WF results to the selected SDGs (step 2). A viable benchmark option was the WF of a product with the same function as chicken meat and data available for comparative purposes [22]. Thus, the WF of fresh chicken meat processing made in Peru, according to Arbaiza and Quispe [19], was chosen as a benchmark for this contribution analysis.

For the contribution analysis (step 3), the blue and grey WFs of chilled chicken meat were compared to benchmarks using a 5-point scale (Table 3). The attribution of a positive score was interpreted as positive contribution of the analyzed system to the related SDG, while a negative score was associated as potential negative contribution. Finally, the results from these comparisons were interpreted (step 4).

3 Results and discussion

3.1 The water footprint of chilled chicken meat

The total WF of chilled chicken was 136.1 liter/kg. It was composed of 0.5% (0.67 liter/kg) of blue WF and 99.5% (135.44 liter/kg) of grey WF. These results showed that potentially much more water was consumed to dilute the wastewater generated than the volumes required for the meat processing.

The low contribution of the blue WF is explained by company returning 91% of the captured water to the same river that supplied this water. The lost fraction of blue water happens in the water treatment (64%), chicken meat processing (scalding – 24%, and chilling – 7.4%), and wastewater treatment (4.6%). The grey WF, on the other hand, was entirely accounted to the wastewater treatment.

Concerning the grey water, despite the effluent treatment, the water returned to the river with a phosphorus concentration of 1,900% higher than the river water. Thus, the additional load of phosphorus needed to be assimilated by the river. Consequently, a larger volume of water from nature was accounted in the calculation of grey WF. However, it is important to mention that the treated wastewater was launched before the collecting point and the current value of phosphorus concentration in the water captured by the company was not available

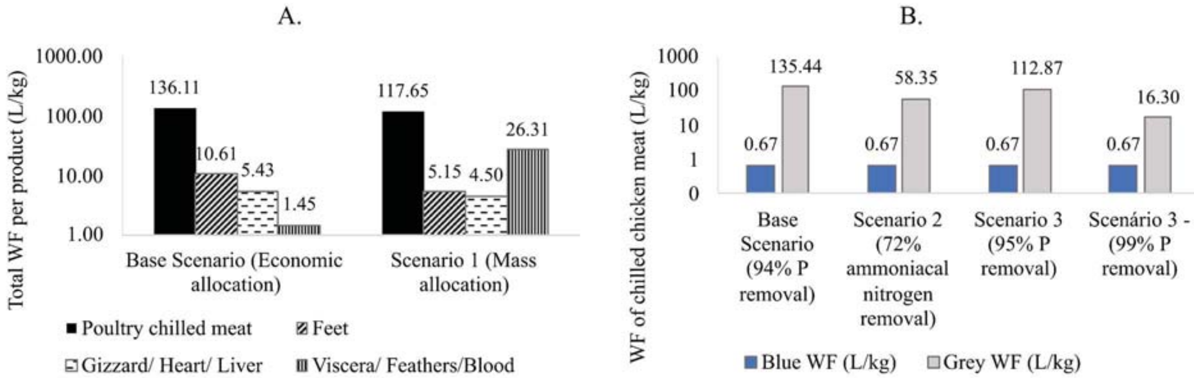

Fig. 3 Results of the sensitivity analysis for Scenarios 1, 2 and 3.

for this study. Because of that, the concentration of phosphorus in the collected water was a parameter with a high uncertainty and has a potential to be different from those used in this paper (0.05 mg/liter).

Previous studies applying the WFN method developed by Palhares [23], Mekonnen and Hoekstra [31], and Ibidhi et al [3] evaluated the WF of chicken production only for agricultural processes. These three studies focused on chicken production at farm level and concluded that the WF of the chicken meat was composed mainly by the green WF, referring to the production of the animal feed ingredients. Ibidhi et al [3] evaluated the Tunisia production of chicken at farm stage, and found a WF equal to 4.7 m3/kg of chicken carcass, and the green WF represented 95.6% of this volume. Palhares [23] estimated an average WF of 1.86 m3/kg of chicken meat for the state of Goiás in Brazil, and 2.1 m3/kg for country level. Mekonnen and Hoekstra [31] found an average of 4.5 m3/kg of chicken meat for Brazil.

Given these data, it is interesting to note that the agricultural phase of WF chicken meat is considerably higher than the industrial phase studied in this work. Considering the WF of chicken production in the state of Goiás (1.86 m3/kg of chicken meat), and the results of this study, the total footprint (agricultural + industrial processes) was 2 m3/kg of chilled chicken meat, agriculture accounting for 93% of this footprint.

Few studies addressed the industrial processing of chicken meat. Arbaiza and Quispe [19] calculated the WF of fresh chicken meat in Lima, Peru, based on the WFN method. The calculated WF recorded the water consumption in the incubation, breeding, and processing of fresh poultry. Arbaiza and Quispe [19] showed that the WF of processing fresh chicken was 168 L/kg, with 88% of this value from grey water, similar to the profile found in the present study. The WF of 136 L/kg of chilled chicken meat found in this study was lower than the value found by Arbaiza and Quispe [19] for fresh chicken meat, and this can be explained by the lack of allocation procedures in the fresh chicken meat study performed by Arbaiza and Quispe [19], and the unclear choice of pollutant used in the calculus of grey water.

3.2 Sensitivity analysis based on scenarios variation

The WF contributions of each product generated by the chilled chicken meat in the baseline scenario (economic allocation) were compared to Scenario 1 (mass allocation), in Fig.3.A. Fig.3.B presented the blue and grey WF of chilled chicken calculated in Scenario 2 (pollutant choice for greywater calculation) and Scenario 3 (phosphorus removal efficiency).

It was notable the influence of Scenario 1 in the WF of viscera, feathers, and blood. This group of by-products presented the second-largest WF among chicken products when mass allocation was used. The reason is the mass of these three products, which represents 17% of the total mass, while their gross economic income represents only 1% of the total income of this system (Table 2).

However, Scenario 1 did not alter the importance of products in the WF results. Although there was a 14% reduction in the final footprint value, chilled chicken meat remained with the highest WF among all generated products. As economic allocation tends to increase the WF of chilled chicken meat, this is suggested for use as a worst reference situation when calculating product WF. For the remaining co-products, mass allocation represents the worst reference situation to calculate WF.

Scenario 2 was developed to assess the grey WF based on ammoniacal nitrogen pollutant. This analysis showed a 57% reduction in the WF of chilled chicken meat (Fig.3.B). This reduction in WF does not represent an environmental improvement in the product system since no changes were made. However, it clearly showed the sensitivity of the WF results to the choice of pollutant in the greywater calculation. A standard for this choice could be helpful to instruct other WF practioners on working with the same product system.

Scenarios 2 and 3 highlight the importance of improving phosphorus removal in the wastewater treatment to reduce greywater volumes from chilled chicken meat. The Brazilian legislation [23] presents a higher standard for phosphorus concentration than for ammoniacal nitrogen. However, the wastewater treatment was less efficient in removing ammoniacal nitrogen (73% removal) than total phosphorus (94%). The higher requirement for phosphorus concentration in water bodies lead to a higher greywater volume.

In Scenario 3, the percentage of phosphorus removal in wastewater treatment was changed from 94% (base scenario) to 95% (using ferric sulfate as a coagulant), and to 99% (using cationic polymers as flocculants). Results showed a significant improvement in the WF, especially when 99% phosphorous removal is achieved (Fig.3.B). The 95% efficiency in phosphorus removal, which is only 1% different from the base scenario could reduce the product WF by 17%, while the 99% removal rate could reduce the WF up to 88%.

3.3 Linking the water footprint results to the UN sustainable development goals (SDG)

The SDG indicators survey considered that the blue and grey WFs of an agro-industrial system can be included as parameters for measuring sustainability (indicator 2.4.1). The blue WF was exclusively considered a relevant environmental indicator to the analysis of water efficiency (indicator 6.4.1), water stress level (indicator 6.4.2), and material footprint (indicators 12.2.1 and 12.2.2) in the 2030 Agenda. On the other hand, the grey WF supports the comprehension of water pollution level by one productive system. Thus, this analysis linked the grey WF to SDG indicators related to the quality of water bodies (indicator 6.3.2), human mortality rate attributed to unsafe water (indicator 3.9.2), and coastal eutrophication index (indicator 14.1.1). In addition, the grey WF can be a relevant parameter to understand the quality of wastewater emitted from the system to the environment, which can affect the proportion of wastewater safely treated (indicator 6.3.1).

Fig.4 shows the summary of Brazilian indicators that can be affected by the results of WF of chilled chicken meat to the SDG indicators measured for the base and third alternative scenarios. The base and third scenarios showed a relatively positive contribution to the selected indicators when comparing this paper with the selected benchmarks. The processing of chilled chicken meat from the analyzed system resulted in a blue WF 97% smaller than the Peruvian production analyzed by Arbaiza and Quispe [19], resulting in a positive 2-point relationship. The blue WF for Scenario 3 was identical to the base scenario (0.67 liter/kg of meat) and also received a positive 2-point score.

Concerning the grey WF, the analyzed system resulted in 9% lower volume of grey water per functional unit when compared to benchmark, resulting in a positive 1-point contribution to the affected indicators. A better result was obtained when the grey WF in Scenario 3 was compared to the benchmark. In this case, a positive 2-point score contribution was achieved because the proposed improvement in wastewater treatment could reduce the grey WF of the system. The improvement in phosphorous removal efficiency from 94% (base scenario) to 95% (Scenario 3) was enough to minimize the grey WF in 25% than the benchmark, characterizing the positive 2-point score. However, considering 99% phosphorous reduction in wastewater treatment, the comparison of Scenario 3 to the benchmark resulted in an 89% difference, drastically increasing the potential of the system to make a positive contribution to the affected SDG indicators.

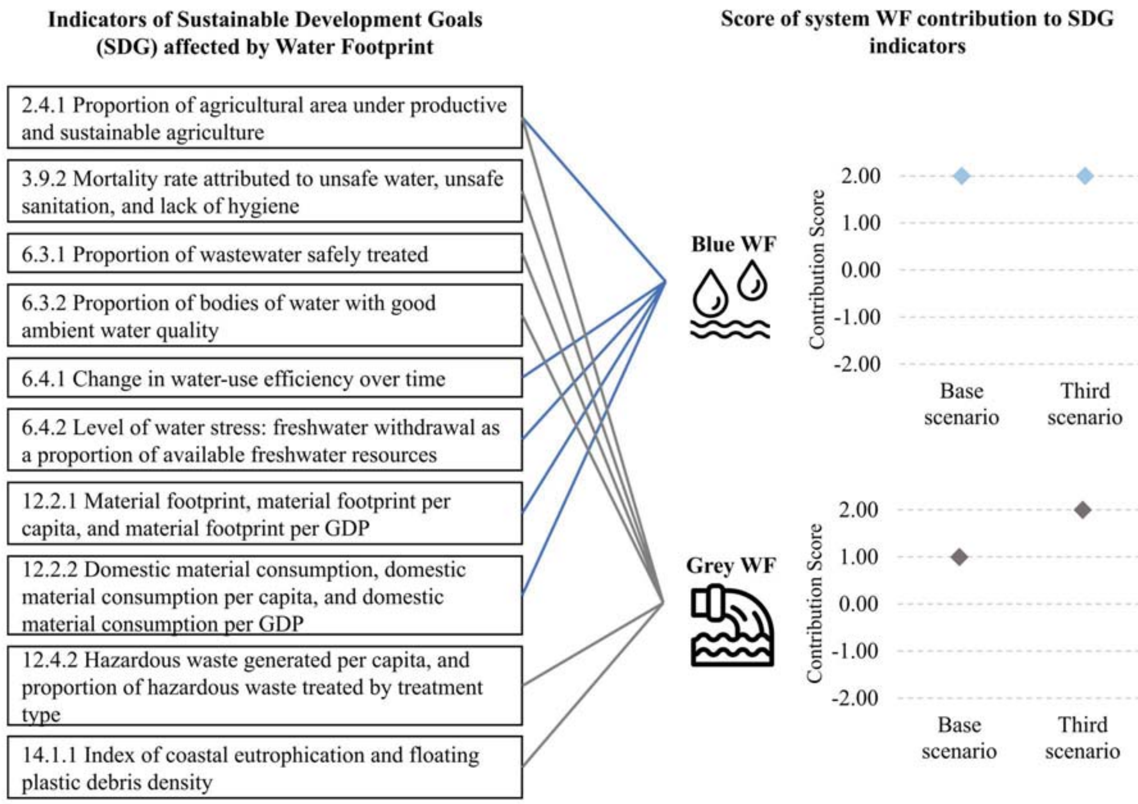

Fig. 4 Relationship between water footprint and the sustainable development goals.

4 Conclusions

This study showed that the WF of chilled chicken meat was 136 L/kg. This footprint was mainly due to the greywater volume related to the dilution of phosphorus load present in the treated wastewater.

The scenario analysis showed that the methodological choices affect the results of the chilled chicken WF, mainly the selection of the pollutants considered for grey WF (Scenario 2). Scenario 3 evaluated the improvement in the wastewater treatment system and showed that the reduction of phosphorus concentration in treated wastewater proved to be a timely way to reduce greywater consumption by the system.

Regarding the contribution of WF to the SDGs, the blue WF of the analyzed system showed a relatively positive contribution compared to the benchmark to the SDGs 2, 6, and 12, which have targets and indicators related to blue water consumption. The grey WF of the system showed a positive contribution to SDGs 2, 3, 6, 12, and 14, which cover targets and indicators related to water quality and pollution.

The WF-SDG joint analysis was beneficial to evaluate the role of chicken meat processing in the search for SDGs related to quality, pollution, and water use. This analysis also evaluated how the improvement opportunities by scenario analysis can influence the system's relationship to the SDG. We concluded that a higher phosphorous removal in wastewater treatment can increase the system's positive contributions to the SDGs related to grey WF.

Finally, for future studies, it is recommended that WF studies should also include the potential impacts on water scarcity. In addition, more studies are desired to combine environmental measures (e.g., WF) with the SDGs, and this paper can be used as an illustrative case to this end.

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