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Water and Land Footprint Assessment of Food Loss: A Case Study on Indonesia

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In Indonesia, the agricultural sector plays a crucial role as the backbone of food security in the country. Like most developing countries, Indonesia also faces many inefficiencies in its agricultural sector, which interfere with its productivity. One of the most common efficiency problems is the high quantity of food loss. Over 8 Mt of food is wasted in Indonesia before it reaches the consumer, resulting in food and agricultural inefficiencies as well as water and land resource inefficiencies, as the agricultural sector relies on these two resources. This study attempted to assess how much water and land are wasted due to food loss in Indonesia. Based on the calculation, Indonesia's food loss annually results in around 14,670 Mm^3 of water loss. Food loss in cereals utilises the highest portion of green water (~6,500 Mm^3), blue water (~600 Mm^3) and grey water (~1,000 Mm^3), followed by pulses and oil crops. Similar to the land footprint, cereals food loss left around 0.70 Mha of land and 0.50 Mha for pulses and oil crops. This result indicates that the government needs to pay special attention to reducing food loss in those food crops and managing its resources during cultivation.

1. Introduction

As a country with a high population and abundant natural resources, Indonesia is highly concerned about its agricultural sector as it has become the backbone of its food sustainability. Due to its reliance to the agricultural sector, the country also relies heavily on land and water resources. Based on data taken from the Ecological Footprint database, Indonesia's dependence on cropland is still quite high, as can be seen from the average Ecological Footprint, which reaches around 66 M gha, or about 30 % of Indonesia's total Ecological Footprint (Figure 1a). Ecological Footprint (EF); is a method used by the Global Footprint Network (GFN) to measure the demand by person, group, or activity on the biologically productive land and water resources. The measurement is measured in global hectares (gha) to accommodate the terms of biocapacity in the global world. This high dependence on cropland also affects the use of production factors and other resources, including the use of water. Approximately 70 % of Indonesia's total freshwater is used and allocated to the agricultural sector (Figure 1b).

The inefficiencies in the agricultural sector may interfere with its productivity. Food loss is one of the most common efficiency problems in this sector due to many inefficiencies in the supply chain, such as poor harvest handling, storage and distribution. In the end, this high rate of food loss also wastes water and land resources, the primary resources for agricultural cultivation (Mopera, 2016).

Every year, Indonesia experiences a loss of around 8 Mt of food (BKP Kementan and BPS, 2020). The number shows that many foods are wasted in the early stages of the supply chain before reaching consumers. The situation is unfortunate because food crop cultivation consumes considerable land and water resources. Due to high food losses, Indonesia has wasted many resources during cultivation. The problem becomes more complicated because Indonesia also faces many challenges in managing its land and water resources. As a humid-tropic country, Indonesia's water use is relatively higher than that of other countries as it needs to provide more water during the dry season, especially for paddy rice, which is always cultivated under constant flooded conditions. More than 30 % of the country's irrigation systems are also damaged or malfunctioning (Bebey, 2019), making controlling and managing water resources challenging and water usage for agriculture in Indonesia very wasteful. In addition to the challenges in water resources management, Indonesia also faces

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difficulties in land provision for food cultivation. One of the main problems is crop productivity stagnation, which often forces the country to exploit more land as cropland. As the need to increase agricultural production is considered a highly urgent matter, under the Food Estate program, the country is planning to utilise some area of peatland to achieve food production targets, which are feared to cause damage to forest ecosystems, increase the risk of peat fires and increase emissions (Sulaeman et al., 2021).

Despite the seriousness of the problem, the awareness of food loss reduction in the country is still low because there are still limited studies that discuss the link between food loss and waste of resources, especially land and water resources. This study assesses the negative externalities of food loss and its connection to waste of land and water resources. By utilising the national statistics on food loss and crop productivity, this study attempts to evaluate the water and land wastage caused by food loss. This study highlights the importance of reducing food loss in Indonesia as it brings with it more significant environmental issues than previously identified.

Figure 1: (a) The Total Ecological Footprint 1990-2018 (Source: GFN (2022)), (b) Total Freshwater withdrawals in Indonesia 1992-2017 (Source: FAO (2022))

2. Data and Method

In this study, the water and land footprint caused by food loss was quantified using the methodology proposed by Kashyap and Agarwal (2020). The water footprint is the amount of water used for production activity. Three water footprints were calculated in this study: 1) *Green water footprint*; rainfall over land that eventually flows back to the atmosphere as evapotranspiration—is the main source of water to produce food, feed, fibre, timber, and bioenergy, 2*) Bluewater footprint*; groundwater and surface water used to grow crops, also often referred to as "water deficit" because it is the amount of water that must be met in addition to the amount of water provided naturally (green water), and 3) *Greywater footprint*; wastewater or the water used or required to dilute pollutants (Hoekstra et al., 2011). The calculation of the Water Loss (WL) is done by multiplying the food loss quantity by the Water Footprint indices (WF), or it can mathematically be written as Eq(1) to (3):

$$WL^i_{green} = WF^i_{green} \cdot F^i_{loss} \quad (1)$$

$$WL^i_{blue} = WF^i_{blue} \cdot F^i_{loss} \quad (2)$$

$$WL^i_{grey} = WF^i_{grey} \cdot F^i_{loss} \quad (3)$$

Where the WL^igreen/blue/grey is the water loss due to the food loss in each food item (i). WF^i green/blue/grey is the water footprint indices. The WF value in this study utilises the indices derived from (Mekonnen and Hoekstra, 2010a) for agricultural crops and (Mekonnen and Hoekstra, 2010b) for animal products (meat, eggs, and dairy products). This study utilises the WF indices for Indonesia. The indices do not cover all agricultural crops in Indonesia, and if the specific indices are unavailable, the value used for wet tropical countries is used. While the F^i is the value of the food loss that derived from Indonesia Food Balance Table (FBT) 2016-2020 derived from BKP Kementan and BPS (2020). The Indonesia FBT consists of 142 food crops and animal products. For conciseness, in this study, those commodities are grouped into seven categories: 1.) cereals, 2.) starchy foods, 3.) fruits, 4.) vegetables, 5.) pulses and oils crops, 6.) sugar, and 7.) meat and dairy. The value for the food loss in 2020 is still a provisional value that might be updated in the future publication.

Besides the water resources, food crops cultivation also demands land resources. The high amount of food loss also describes the inefficiency in land management. This inefficiency is usually calculated and described as

Land Loss or Land Footprint Loss. The land loss (LL) that is associated with the food loss is calculated as the division of wasted food divided by the crop's yield (Y^i), or it can be mathematically written as Eq(4):

$$LL = \frac{F^i_{loss}}{Y^i} \quad (4)$$

Similar to the calculation of the water loss, each food item is aggregated into several food groups. However, this study exempts the LL calculation from the livestock due to the different definitions and treatments of productivity between crops and livestock that are still not accommodated in this study. For the livestock, the productivity is based on its reproductivity speed and size. The calculation also needs to consider the natural and cultivated pasture land. The crop yield information is compiled from the Indonesia Ministry of Agriculture statistical database (Kementerian Pertanian, 2020a). Most of the information on crop yields in 2020 is still unavailable. In that case, the yield is calculated by dividing the total quantity of harvest by the harvest area.

3. Result

3.1 Water Loss

In the past five years, Indonesia's food loss annually results in around 14,670 Mm^3 of water loss, consisting of 12,500 Mm^3 of green water, 770 Mm^3 of blue water, and 1,400 Mm^3 of greywater (Figure 2). Based on this calculation results, food waste from the cereals crops wastes the most water. This can be seen from the number of green, blue, and grey water footprints produced by cereal loss. This result is quite similar to the global trend that the cereal crops (especially paddy) become a major contributor to water loss, especially blue water due to the high reliance on irrigation water and greywater due to the excessive amount of chemicals, like fertiliser during the production (Kummu et al., 2012).

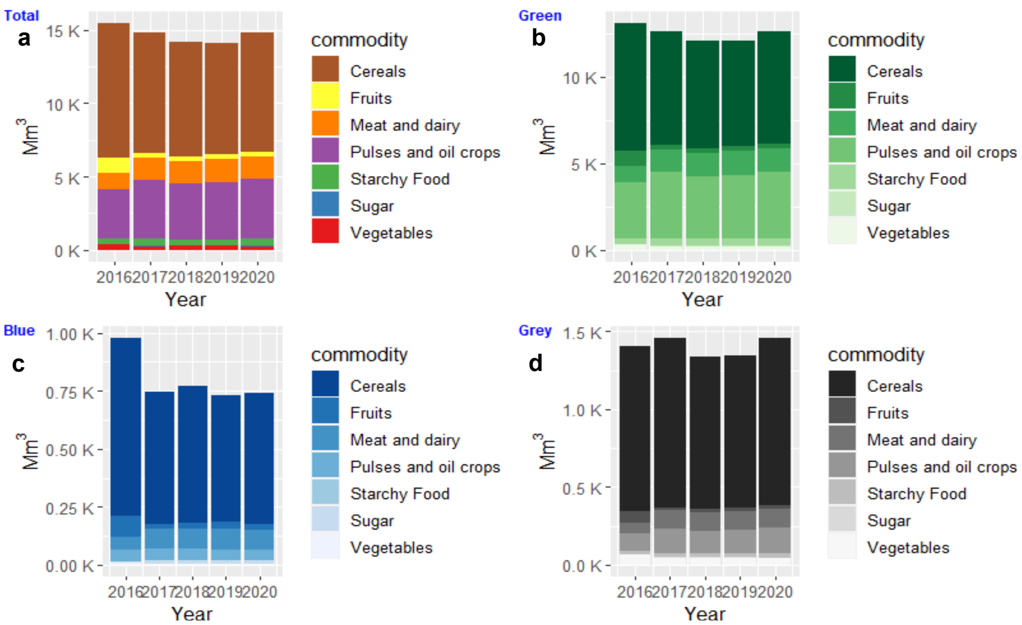

Figure 2: The calculation result of Water Footprint associated with the Indonesia Food Loss 2016-2018. Illustration of (a) total water loss, (b) green water loss, (c) blue water loss, and (d) grey water loss

The average amount of water wasted from cereal crops is about 6,715 Mm^3 of green water, 640 Mm^3 of blue water, and 3,129 Mm^3 of greywater. This value aligns with the performance of food loss in Indonesia, which is dominated by cereals, mainly paddy. Paddy rice is the most problematic crop in the country. As rice is the main staple food for the country, it is cultivated throughout the country. Many subsidies are also applied to support the cultivation of this crop. However, the productivity of these crops also stagnated due to land competition. While around 40-50 % of food loss in Indonesia also comes from the paddy sector, signalling a high inefficiency of these crops (Malahayati and Masui, 2021). This condition is getting more serious because rice cultivation techniques are still quite conventional, considering that smallholder farmers still dominate the rice farming sector in Indonesia. This conventional farming technique requires much water, and the rice fields are constantly flooded. A large number of damaged agricultural irrigation also makes it difficult to regulate the amount of water for irrigating rice fields.

Lack of food loss reduction technology has resulted in the amount of water loss from cereals food groups not experiencing a significant change over the last five years. It can be seen from the number of green and blue water losses for cereal commodities which are relatively stagnant (see Figures 2b and 2c). Figure 2c shows that the blue water loss in 2016 was the highest due to the drought as the El Niño phenomenon that hit Indonesia in August 2015 and continued by 2016. This situation also shows that during the dry and drought condition, Indonesia needs to supply more irrigation water. As many agriculture irrigations in the country are broken and malfunctioned, water use becomes inefficient, and more blue water is wasted during the drought. An interesting finding from this study is that food loss in pulses and oil crops in Indonesia contributes to the second largest water loss after cereal crops. In total, around 3,710 Mm^3 of water consists of 3,526 Mm3 of green water, 48 Mm^3 of blue water, and 136 Mm^3 of grey water, wasted annually due to food loss pulses and oil crops commodities.

Palm oil and soybeans are commodities that cause high levels of water loss in this food group. As the world's largest palm oil producer, Indonesia has extensive palm oil plantations to meet domestic and international demands. Palm oil demands much water, making this crop grow well in tropical regions with very high rainfall, like Indonesia. As palm oil mostly uses green water that is relatively more sustainable, there are no significant issues with the sustainable use of water. However, as the production is more massive to fulfil the industrial demand, there are more land openings for palm oil plantations, which usually also includes the opening of forest areas and peatlands that create deforestation and demand more water resources (ILSI, 2011). Also, like cereal crops, many inefficiencies still happen in the Indonesian palm oil plantation. Approximately 40 % (around 6 Mha) of oil palm plantations in Indonesia are managed by smallholder farmers who still use simple postharvest technologies to harvest and manage their palm oil, resulting in wasting production factors, including fertilisers and water (Putra et al., 2019).

Soybean is also the main pulses commodity in Indonesia as it is the main vegetable protein in the country. However, the inefficiency in Indonesia's soybean is also very high, and the country is struggling to achieve its production target and fulfil domestic demand. To fulfil its domestic demand, Indonesia imports 60 % of soybean (Kementerian Pertanian, 2020b). On the other side, around 150,000 t of soybeans are wasted annually. This amount equals 6 % of Indonesia's annual total soybean imports. The high food loss from the soybeans adds to the total water loss in pulses and oil crops, especially because the soybean's cultivations and productivity maintenance demand a sufficient amount of water. To maintain the soybean's productivity, this crop needs regular irrigation. Around 300 and 600 mm/season of water is needed to maintain its production level (Taherzadeh and Caro, 2019). Soybeans also need more intensive watering during the flowering and pod-filling phases. Along with the increasing number of drought cases in Indonesia, soybeans in Indonesia need more water than before and even require additional costs to finance additional workers to help with irrigation processes or to pump water from rivers, causing the high cost of cultivating soybeans (Herawati et al., 2018). The high cost of production also causes the low adoption of technology to reduce the level of food loss, which also means that the level of water loss is still high caused by this commodity, especially irrigation water (blue water).

3.2 Land Loss

Land loss in this study describes the inefficiency of the land resource utilisation associated with wasted food. The land loss associated with the food loss in Indonesia during 2016-2020 was 1.9 Mha (not including land for livestock/ pastureland). The biggest annual loss was faced by the cereal crops (around 0.9 Mha), pulses and oil crops (0.6 Mha), and vegetables (0.3 Mha) (Figure 3). The loss of 1.9 Mha of land because the food loss is a big number. It is equivalent to seven times the average soybean harvested area (Kementerian Pertanian, 2020b) or half of Indonesia's average maise harvested area (Kementerian Pertanian, 2016). This result is triggered by the land use pattern in Indonesia that is highly used to cultivate food crops (mostly paddy and other cereals) and oil crops (especially palm oil). The problem is that there is a trend of stagnant yield improvement of cereals and palm oil in the country. In the case of palm oil, although Indonesia is the biggest producer of this commodity in the world, the yield is low, even compared to the other main producer, Malaysia. While the yield of palm oil in Malaysia can reach around 4- 5 t/ha of CPO per year, the yield of Indonesian palm oil is only around 3.5- 4 t/ha of CPO per year (Khatiwada et al., 2018). This condition makes Indonesia tends to exploit more land to fulfil its production target. As the production process is also inefficient, the level of loss from this sector is still very high. If it is converted to the land footprint value, the palm oil sector contributes to the high cropland loss in pulses and oil crops. Vegetables also contribute a high proportion of land resource loss. Like paddy and palm oil, horticultural commodities in Indonesia, especially vegetables, have stagnant yields and tend to decline. This is one of the effects of climate change which causes many crop failures and reduces land productivity for vegetable commodities. Vegetable crops are more sensitive to climate change than other horticultural crops, such as fruits.

Scheelbeek et al. (2018) show that a 4 °C increase reduced mean yields of vegetables and legumes by−31.5 %.

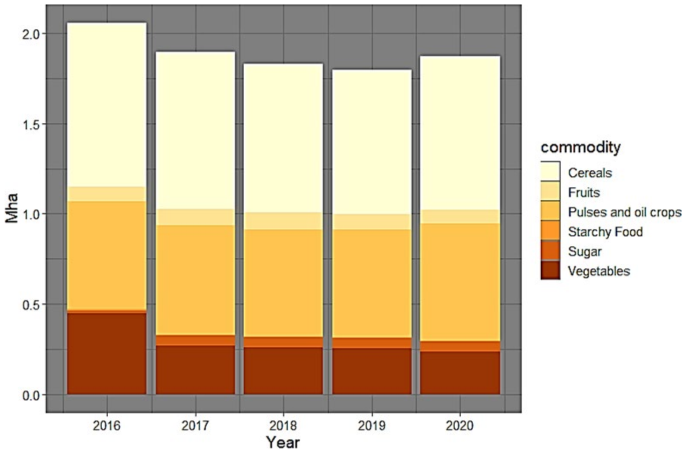

Figure 3: The calculation result of Land Footprint associated with the Indonesia Food Loss 2016-2018 (in Mha)

4. Policy implication

From the findings, it is clear that the high amount of food loss in Indonesia leads to the significant loss of water and land resources. With this condition, Indonesia not only has to pay special attention to reducing food loss but also needs to find ways to minimise the level of water and land resources loss. Food loss reduction is the most critical step and sustainable solution. The Indonesian government should quantify food loss more accurately, measure the possible environmental effects and adopt appropriate policies according to the situation. For example, food loss in the cereals sector has been a serious problem for decades. However, it has still not been possible to significantly reduce the loss in this sector. As the agricultural sector in Indonesia is mainly cultivated and managed by smallholder farmers, it is essential to increase the penetration and introduction of more advanced postharvest technologies to increase their efficiency. Moreover, it is also important to introduce farmers to the economic and environmental benefits that they can achieve by having a more efficient harvest and postharvest system. This is because, in most cases, around half of the smallholder farmers in developing still use traditional harvest and postharvest methods due to convenience and are unaware of the benefits of introducing a more modern method to farming (Stathers et al., 2013).

According to this study, the Indonesian agricultural sector loses more than 14,000 Mm^3 of water yearly along with food during the postharvest stage, which is extremely detrimental to farmers and the Indonesian agricultural sector. However, it is possible to reduce water loss gradually. One possible way is by recycling the greywater to be used as irrigation water, as the study conducted by Rodda et al. (2011) shows that although greywater is often considered polluted water, in most cases, this water still has important compounds and can still be used for crops. To reduce the chemical compound of grey water, the farmers can mix it with blue water (tap or irrigation water). By utilising greywater, the farmers can minimise further production factor loss during agricultural cultivation. There is also a concern regarding land resource loss. In addition to decreasing food loss, increasing yields for essential agricultural commodities could be the key to curbing land resource loss. With the advancement of agricultural technology, there is still a lot of room for productivity improvement for agricultural commodities, especially for horticultural crops (fruits and vegetables) and plantations (e.g., palm oil).

5. Conclusion

This study estimates the wasted water and land resources caused by food loss of major food groups in Indonesia during 2016-2020. The result shows that Indonesia's average food loss results in around 14,800 Mm^3 of water loss and 1.9 Mha of land loss. Among all the food crops, cereals' food loss (dominated by paddy rice) accounted for the largest portion of the water loss (around 53 % of total annual water loss), followed by pulses and oil crops (25 % of total annual water loss). The intensive use of flooded irrigation systems in rice cultivation in Indonesia becomes the main driver of the high water footprint this commodity leaves. At the same time, the food loss in Indonesia is also dominated by the cereals sector. Around 5 million cereal crops were wasted annually in the supply change's early stage. The situation leads to a high and significant production factor loss, including fertiliser and water. It also creates a high waste of land resources, as around 0.9 Mha of land can be saved if all of the food loss in cereals crops can be fully handled.

From this study, it can be seen that the high level of food loss in Indonesia also leads to high water and land loss levels, that food loss prevention very important to minimise the waste of existing resources. In addition, the government can consider several policy options. To reduce water loss, Indonesia can use grey water for land irrigation. The policy will be very beneficial, especially during droughts, when Indonesia demands more supply from the irrigation, especially with the current situation, where a lot of agricultural irrigation is damaged. In addition, for the land sector, increasing crop yields can be one of the key policies to reduce the amount of land exploitation for planting food crops.

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