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International Cereal Trade of Bangladesh: Implications for Virtual Land, Water, and GHG Emissions from Agriculture

Parmeshwar Udmale*, +, Indrajit Pal+, 1, Sylvia Szabo*, and Malay Pramanik*

Abstract – *The study aims to get insights into virtual land, water flows from producers' perspectives for cereal crops and trade in Bangladesh and provides insights into the carbon emissions from agriculture. For this purpose, FAO's cereals area, production and yield, food balance sheets, detailed trade matrix, GHG emissions, and population data for the year 2014-17 were used. Cereal water footprints data were obtained from the secondary literature. The study finds that 8% of domestic cereal supply (70% wheat, 17% maize, and 2% rice and related products) was imported through international trade. The annual average virtual cropland area and water imported through trade of 6.9 million tonnes of the three cereal crops (excluding products) were 2.1 million ha and 14 billion m3, respectively, during 2014-17. Bangladesh would need additional 2.81 million ha land and 12 billion m3 water to be cereal self-sufficient. Energy used in agriculture, including mechanization and irrigation, adds to GHG emissions, and there is potential to use renewable energy sources to reduce the GHG emissions from agriculture. An integrated management of water, energy, and carbon should be considered as one of the strategies to reduce GHG emissions from agriculture.*

Keywords – *Bangladesh, carbon trade, greenhouse gases, international crop trade, water-energy-food nexus*

1. INTRODUCTION

Greenhouse gas (GHG) emissions and water consumption in a globalized world are becoming important indicators for policy and decision making [1]. With increasing population and economic development, water use in domestic, industrial, and agricultural sectors has increased, in turn accelerating energy consumption in the treatment and transport of water. Energy is used in various stages of water use, such as abstraction, conveyance, water treatment, and treatment of sewage water after water is used to sustain the ecosystem. So far, agriculture consuming the highest amount of water, which is about 70% of water extractions from aquifers, lakes, rivers, and ponds, even in an unsustainable way [2]. The Food and Agriculture Organization (FAO) [3] projected that the use of irrigated and rainfed agricultural water consumption by 2050 would increase by 19%. However, this could be far higher if agricultural production efficiency and crop yields do not increase dramatically. This abstraction exceeds local availability and accessibility of renewable water, and irrigation depletes the groundwater supplies [4].

Pre-industrial societies used agriculture as an important consumer of energy and practically as the only cause of mechanical power until the Industrial Revolution [5]. Mechanization, chemical fertilizer, synthetic pesticides, and high-yielding seeds are primary causes for the increase in intensive energy usage in agriculture systems. Energy use in farming activity is accounted for in the building and energy and transport sectors included in the UNFCCC framework [6]. The energy transition challenge calls for re-recognizing agriculture as a source of energy, which can deliver food and bioenergy to society as an alternative to fossil fuels. In agriculture, energy consumption is increasing because of the increasing, the rapid growth of population, limited supply of arable lands, and improved living standards [7]. However, recent agriculture activity relies heavily on fossil fuel themselves, and so is far from considering a renewable energy system [8]-[10]. The study of agriculture systems' aspects of land, water, and energy metabolism can provide insights into systemic energy surpluses or deficits and the dynamic connections between productivity and energy inputs.

Agriculture is the key economic sector, which is responsible for crop and livestock activities for primary food production. Since 1970 human population has been rising from 3.7 billion to over 7.0 billion [11], and higher use followed by a transition in diet to more animal products has meant more than doubling agriculture production [12]. As such, it contributes significantly to global warming and climate change. Carbon dioxide (CO_2), methane (CH_4), Nitrous oxide (N_2O), Fluorinated gases (F-gases) are the key GHG emitted by anthropogenic activities. CO_2 is mainly emitted from the burning of fossil fuels and industrial processes. Agriculture activities, including deforestation, soil management, cultivation, fertilizers, energy use, agricultural waste management, and crop burning, as well as livestock and manure management, can emit CO_2, CH_4, and N_2O [13], [14]. The current estimate of

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23 % of total anthropogenic GHG emissions comes from agricultural growth, forestry, and land-use conversion [13].

Recently it has, however, been seen that world agriculture in terms of GHG emissions is becoming more efficient. Emissions are decoupled increasingly from production as production has proliferated. In 2007, the average global carbon footprint per unit livestock and the crop produced were declined by 44% and 39% than 1970, respectively [13, 15]. According to the Intergovernmental Panel for Climate Change (IPCC), agricultural production was estimated to be 10–12% of the world anthropogenic GHG in 2005, while direct non-CO_2 GHG emissions from farming amounted to 56% of the world non-CO_2 [13]. These emissions do not include other food-related emissions directly and indirectly but originated outside of the farm gate. For example, agriculture is linked to land use and land cover (LULC) changes, i.e., peatland drainage and deforestation, which generate GHG emissions similar to those generated by the farm activities globally.

The change in frequency and magnitude of rainfall is likely to cause a change in global water distribution and food production systems. This will increase not only the energy needs for the transportation of water but also food, mainly through international trade [16]. About 23% of food consumed is traded internationally [17]. Therefore, the concept of virtual land, water, and GHG (expressed in CO_2 equivalent) termed as carbon footprint has evolved [18], [19]. Land and water footprint are defined as the land and water embedded in a product throughout the process of production, respectively.

Similarly, carbon footprint is the total GHG emissions caused by a product, expressed as CO_2 equivalent. The virtual land, water, and carbon emissions are defined as the amount of land, water, and carbon embedded in the traded products between two regions. Food traded internationally could significantly reduce the pressure on the local land, water, and energy used for agricultural systems. GHG emissions could be transferred from one region to another in the form of international trade of goods and services, agriculture crops, and livestock. Peters *et al.* [20] reports major source of carbon flows through trade were fossil fuels (37% of global emissions), CO_2 embodied in traded goods and services (22% of global emissions), crops (31% of total harvested crop carbon), petroleum-based products (50% of their total production), harvested wood products (harvested wood products (40% of total round wood extraction), and livestock products (22% of total livestock carbon) in 2004.

Identifying the land, water, carbon footprints (energy) of a crop is an essential component of sustainable agriculture, reducing the resource use per unit crop production [21]. Developing countries have put a strong emphasis on decreasing GHG emissions from agriculture sectors in their mitigation. Most countries with Intended Nationally Determined Contributions (INDC) do not specify the measures intended to achieve their broader emission targets. For example, measures adopted to decrease emission from enteric fermentation, manure management, or managed soil or livestock or cropland-based management contributions [22] or adoption of improved irrigation techniques and clean energy or offsetting the land, water and carbon by importing food crops from other countries having surplus production as highlighted in [16]. In this context, the present study aims to assess virtual land and water flows through cereal crop imports in Bangladesh based on resources used per unit cereal crop (wheat, rice, and maize) and trade volume component of the food (cereal) balance. Besides, the present study quantifies the scenario of Bangladesh being cereal crop self-sufficient and its implications to the country's agricultural land, water, and potential GHG emissions from agriculture.

2. DATA AND METHODS

For cereals area, production and yield, food balance sheets, detailed trade matrix, population data are downloaded from FAOSTAT [12]. The green, blue, and grey water footprints for cereal crops (wheat, rice, and maize) per tonne at sub-national levels are obtained from Mekonnen and Hoekstra [23]. The blue water footprint is the volume of surface and groundwater consumed in the form of evaporation to produce crops; the green water footprint is the rainwater consumed by a crop. The grey water footprint of a product is defined as the volume of freshwater that is required to assimilate load of pollutants based on existing ambient water quality standards [24]. The subnational scale water footprints are averaged to obtain national scale water footprints. Some of the countries do not have water footprint data. Therefore, the global average water footprints are used in the analysis of import volumes from those countries. The total agricultural greenhouse gas emission (GHGs) expressed in CO_2 equivalent (CO_2e) is obtained from FAOSTAT [12]. Virtual land and water are calculated from producers' perspectives based on resources used for per unit crop production and crop trade volume based on detailed trade matrix using the following equations:

$$\text{Virtual land (ha)} = \text{Volume of crop traded (tonnes)} / \text{Crop productivity (tonnes per ha) of partner country} \quad (1)$$

$$\text{Virtual water } (m^3) = \text{Volume of crop traded (tonnes)} \times \text{Water footprint } (m^3/\text{tonnes}) \quad (2)$$

The average world factor to convert paddy rice (FAO Item Code 0027) to husked rice (FAO Item Code 28(a)) is 0.77 (in the range of 0.70 to 0.85) and to milled rice (FAO Item Code 0031(b)) is 0.67 (in the range of 0.60 to 0.70) [25]. The detailed trade data available in milled rice volume is converted to paddy rice by using a

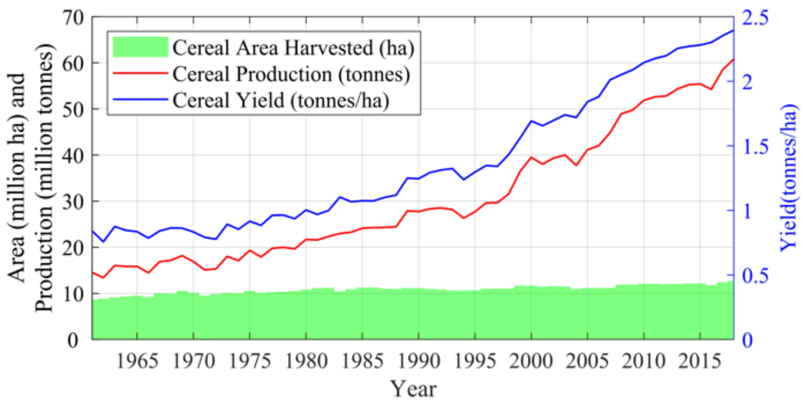
1/0.67 factor. The average area harvested and the average yield of major import partners of Bangladesh are used for the countries, which had missing data. The virtual land and water flows imported through the wheat, rice, and maize are analyzed considering the average of 2014-2017 area harvested, production, yield, and import data as the latest trade data were available till 2017. Bangladesh has a relatively less volume of export of cereal crops compared to its import. Hence study primarily focuses on the import component of national food (cereal) balance. The area harvested, yield, and water footprints for wheat, rice, and maize in Bangladesh context are used to estimate land and water needs based on the country's cereal self-sufficiency scenario. The GHG emissions from agriculture are analyzed based on FAO data. Irrigated area, number and type of irrigation pumps, and energy consumption in agriculture are obtained from Mottaleb *et al.* [26] and FAOSTAT [12]. Potential opportunities to reduce GHG from agriculture are discussed with reference to literature.

3. RESULTS

3.1 Cereals Area, Production, and Yield

In Bangladesh, about 99.7% of the total harvested area for cereals (12.66 million ha) in 2018 is for rice (here, rice=paddy), wheat, and maize. Like many other south and south-east Asian countries, rice is the staple food in Bangladesh. Rice accounts for 70-80% of the total cropped area of the country. In 1961, rice area harvested, production, and yield were 8.5 million ha, 14.4 million tonnes, and 1.7 tonnes per ha, respectively, which increased by 1.4, 3.9, and 2.8 folds, respectively, over 1961-2018 (Figure 1b). In 2018, the rice area harvested was 11.9 million ha, with a total production of 56.4 million tonnes (almost 93% of total cereal production in the country). Rice plays a significant role in securing countries' food supply and sustaining the agricultural economy. Rice crop is grown in three seasons a year in Bangladesh. It has about 80% share in the total irrigated area of the country. Wheat is the second most-produced cereal crop in Bangladesh. However, its area harvested and production is less than rice. The wheat area harvested and production increased from 0.05 to 0.35 million ha, and 0.03 to 1.1 million tonnes, respectively, over 1961-2018 (Figure 1c). Similarly, maize area harvested and production have increased from 9 to 400 thousand ha, and 7 thousand tonnes to 3.3 million tonnes, respectively, over 1961-2018 (Figure 1d).

While considering the country's cereal balance, the average domestic cereal supply was 374 kg/capita/year during 2014-17, of which 92% was domestic production and 8% imported through international trade. The average domestic cereal supply of rice (including rice products) was 323 kg/capita/year during 2014-17, which share 86% of the domestic cereal supply. Similarly, average domestic supplies of wheat (including wheat products) and maize (including maize products) were 32 and 19 kg/capita/year during 2014-17, respectively. Out of these domestic supplies, about 70% and 17% of domestic wheat (including wheat products) and maize (including maize products) supplies, respectively, were imported through international trade. Only 2% of domestic rice (including rice products) was imported through international trade (about 1.3 million tonnes). With the increasing trend of cereal area, production, and yield, the inputs to agriculture such as mechanization, fertilizer applications, and irrigation needs are increasing water, energy, and carbon footprints from agriculture.



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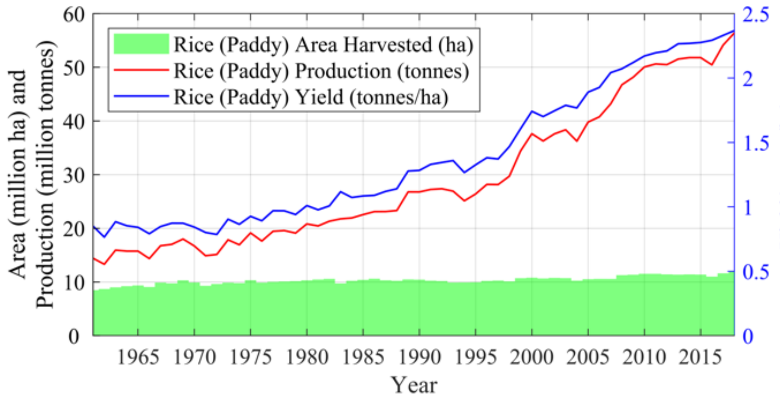

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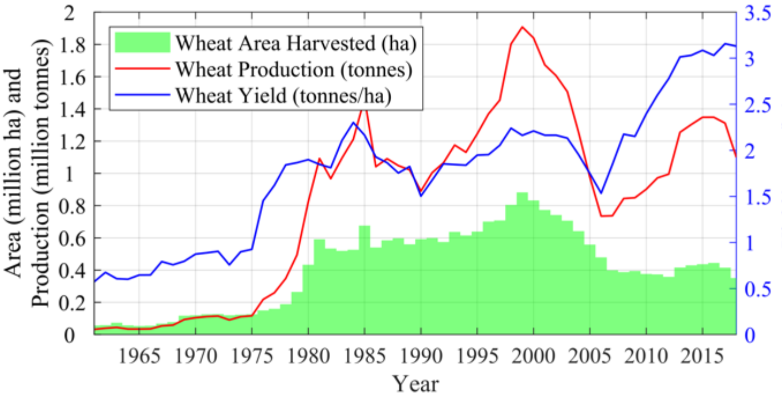

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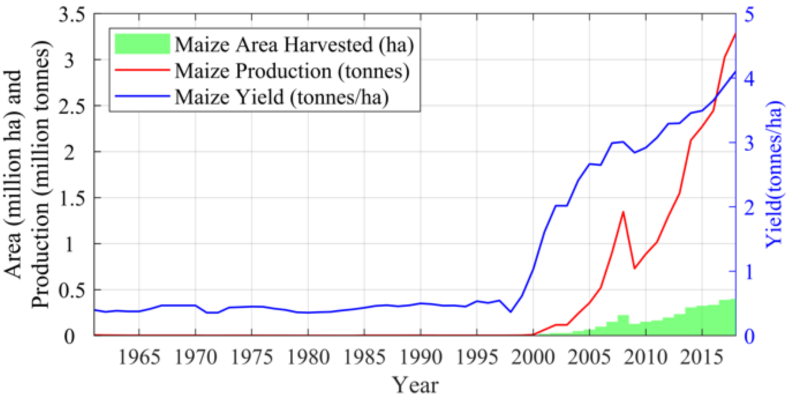

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Fig. 1. Trends in area harvested, production and yield for (a) Total Cereals (b) Rice, (c) Wheat, and (d) Maize crops in Bangladesh from 1961 to 2018.

3.2 International Cereal Trade: Virtual Land and Water Import

The global average cereal water footprint (including green, blue, and grey) is 1644 m^3/tonne. The global average water footprints of rice (paddy), wheat, and maize are 1809, 1469, 1423 m3/tonne, respectively. In Bangladesh, the average water footprints of rice (paddy), wheat, and maize are 1672, 1827, and 1222, respectively. FAO detailed trade matrix data for rice (milled), wheat, and maize were used for analyzing Bangladesh's international trade with major partner countries across the world. The rice milled was converted to rice paddy (FAO Item Code 0027) using (1/0.67) conversion factor.

Annually, Bangladesh imported 1.3 million tonnes of rice (paddy) with 0.36 million ha virtual land and 2.87 billion m^3 of virtual water import through rice during 2014-17. India, Thailand, and Vietnam were the top rice exporters in Bangladesh, with 99% of rice imported from these three countries (Figure 2). Wheat was the largest imported cereal with an average annual import of 4.82 million tonnes. About 96% of Bangladesh's wheat import was from Ukraine, Russian

Federation, Canada, India, Argentina, Australia, and the USA during 2014-17. Annually, Bangladesh imported 1.53 million ha virtual land and 9.77 billion m^3 of virtual water through wheat import (Figure 3) during 2014-17. Bangladesh imported 0.81 million tonnes maize/year during 2014-17. About 91% of maize import was from Brazil, India, and the USA. The country imported 0.17 million ha virtual land and 1.35 billion m^3 virtual water through maize import (Figure 4). During 2014-17, the annual average virtual cropland harvested area and water imported through trade (import) of 6.9 million tonnes of the three cereal (excluding products) crops were 2.1 million ha and 14 billion m^3, respectively. In case of the scenario of Self-sufficient Bangladesh in cereals (rice, wheat, and maize), the country will need an additional 2.81 million ha land for cereal crops and 12 billion m^3 (blue, green, and grey) water, which will increase the GHG emissions from agricultural activities such as mechanization and irrigation.

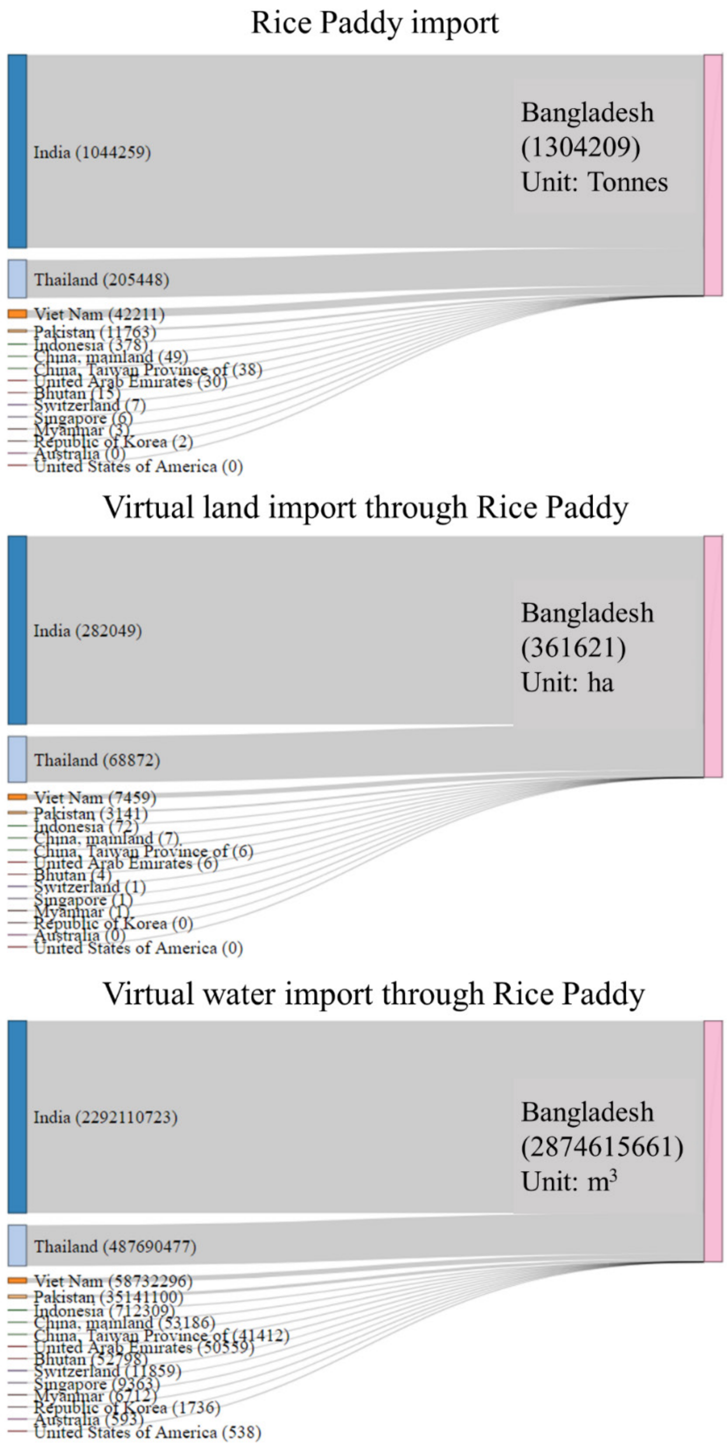


Fig. 2. Annual average Rice (Paddy) import, virtual land, and water flow through rice import in Bangladesh from 2014 to 2017.

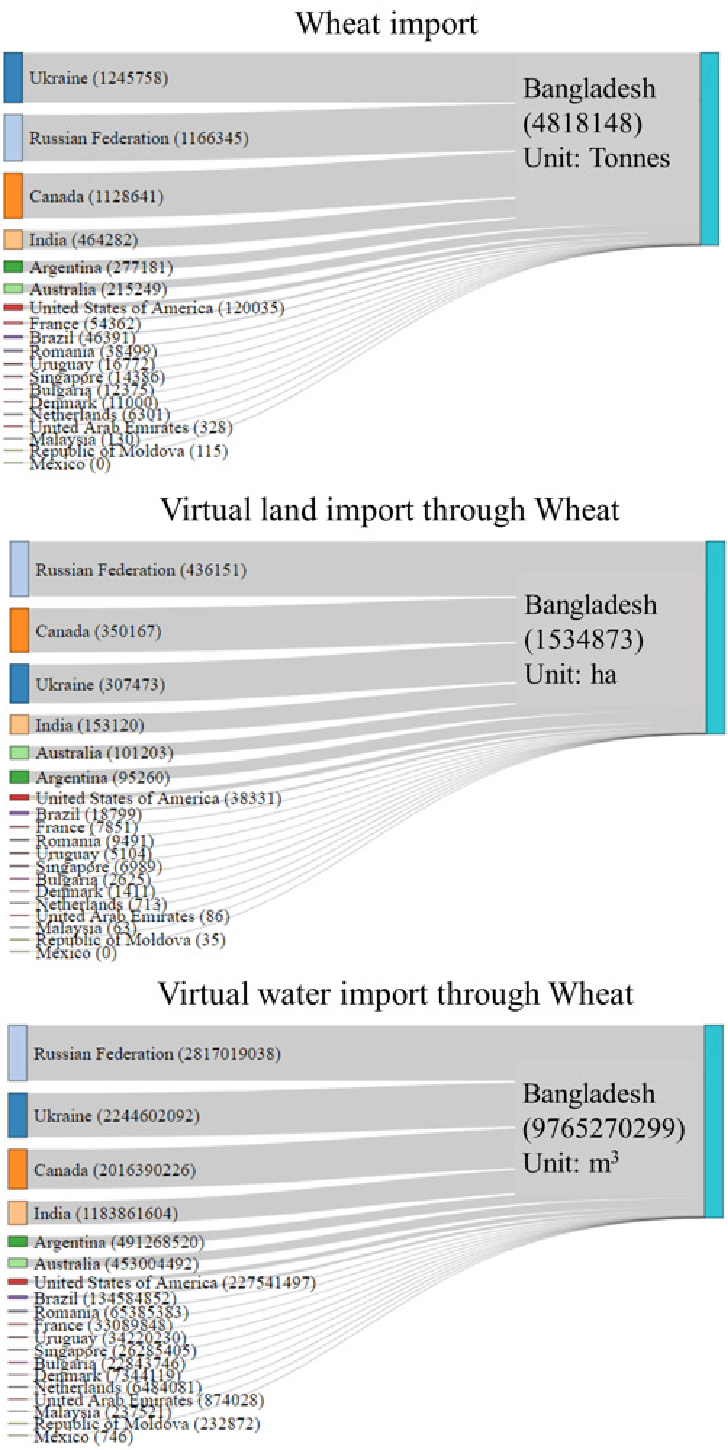


Fig. 3. Annual average Wheat import, virtual land, and water flow through rice import in Bangladesh from 2014 to 2017.

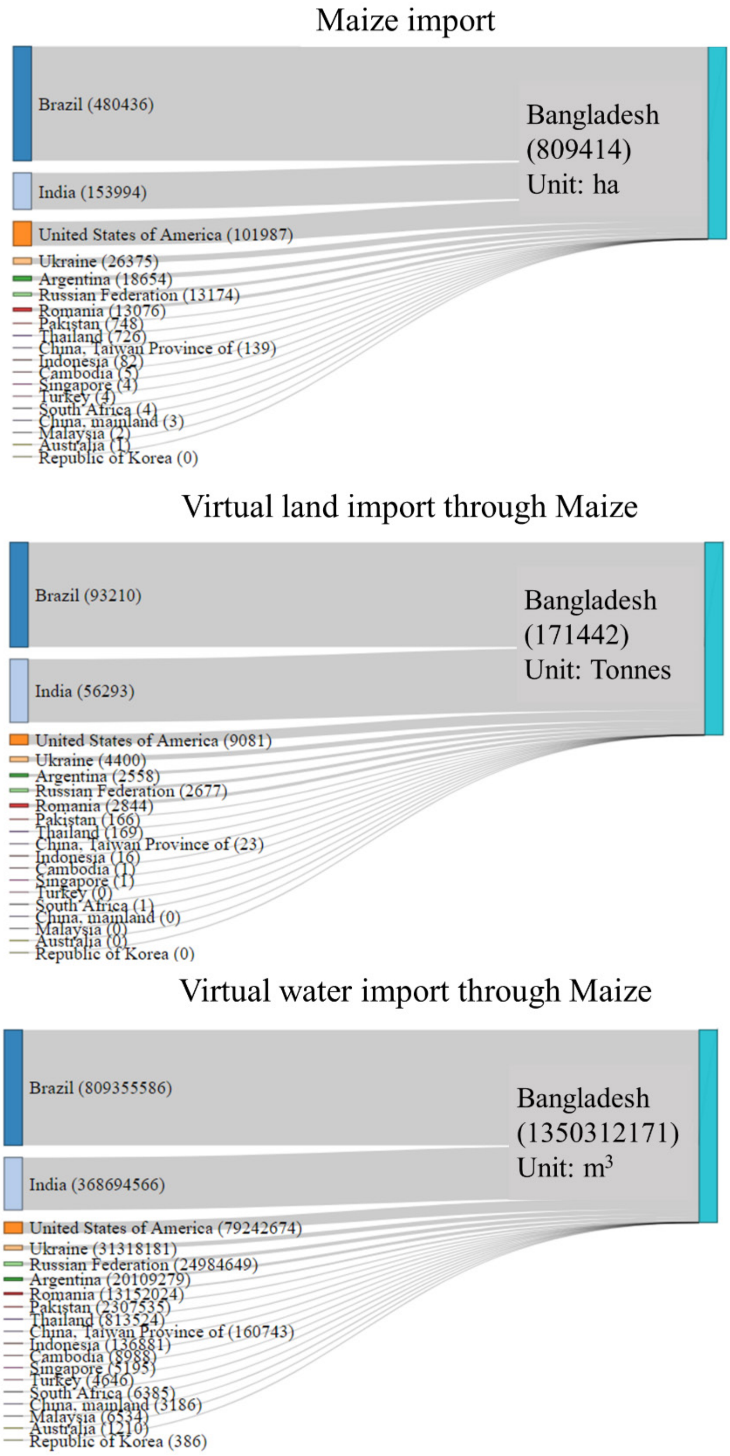


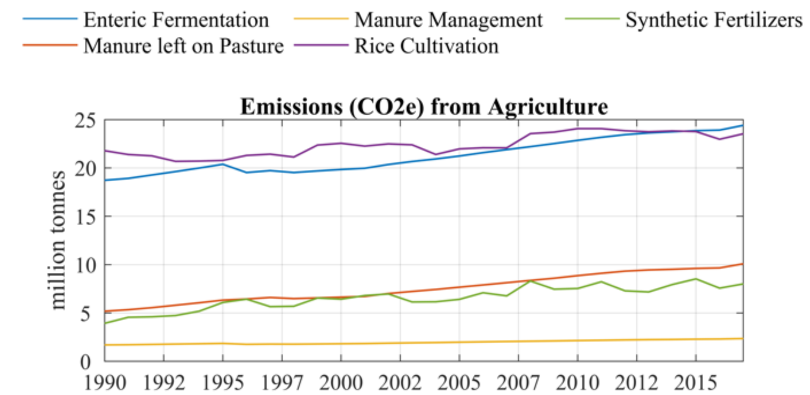
Fig. 4. Annual average maize import, virtual land, and water flow through rice import in Bangladesh from 2014 to 2017.

3.3 Energy Consumption and Carbon Emission from Agriculture

With an increasing trend in the crop area and yield, Bangladesh's GHG emissions from agriculture have increased from 58 million tonnes CO_2e (Mt CO_2e) in 1990 to 77 Mt CO_2e in 2017. Rice is the major crop grown in Bangladesh, with 93.8% share in total cereal area harvested in 2018. Rice is the major contributor of GHG emissions from agriculture. A study by Kritee *et al.* [27] reports that about one-half of all crop-related global greenhouse gas emissions in agriculture comes from rice cultivation. Enteric fermentation (methane emissions from ruminant animals) contributed 24.4 Mt CO_2e, and rice cultivation contributed 23.5 Mt CO_2e to GHG emissions from agriculture, which is 32% and 30% of total emissions from agriculture in 2017, respectively (Figure 5a). Manure left on pasture and synthetic fertilizers contribute 10 Mt CO_2e and 8 Mt CO_2e to GHG emissions from agriculture in 2017, respectively.

Apart from agricultural carbon emissions from enteric fermentation, rice cultivation, manure, and fertilizers, energy used in agricultural mechanization and irrigation, mainly from fossil fuels, also contributes to carbon emissions. Bangladesh's irrigated land has increased from 1.52 million ha in 1982-83 to 5.5 million ha in 2015-16 (Figure 5b). A study by Zou *et al.* [28] estimates GHG emissions from energy used in irrigation, which includes water pumping and conveyance, accounts for 50 to 70% of total emissions from energy use in the agriculture sector. In 2015-16, Bangladesh had 1.72 million irrigation pumps (includes seep tube wells, shallow tube wells, and low lift pumps). The number of irrigation pumps shows a 12-folds increase from 1982-83 to 2015-16. With increased irrigated area and number of irrigation pumps, the energy consumption in agriculture has increased from 4550 terajoules in 1982 to 53668 terajoules in 2012 (Figure 5c).

The proliferation of the number of shallow tube wells has increased energy consumption in irrigation. The majority of irrigation pumps use gas-diesel oil and electricity for the operation of irrigation pumps, causing an increase in carbon emissions. Figure 5d shows that GHG emissions from energy consumption in agriculture. Emissions from gas-diesel oil use in agriculture, mostly for irrigation, have increased from 1.27 Mt CO_2e in 1995 to 3.83 Mt CO_2e in 2012 (about 3-folds increase). The increased need for agricultural mechanization and irrigation could increase the future energy consumption contributing to an upsurge in GHG emissions. Currently, GHG emissions are measured at producers' perspectives; hence the carbon embodied in import is not counted at national level emissions. However, more growth in the domestic agricultural area and crop production could add more pressure on land, water, energy use, and an increase in GHG emissions. In the scenario of Bangladesh-being cereal self-sufficient, the additional land, area harvested, water, and irrigation needs could add to the National GHG emissions.



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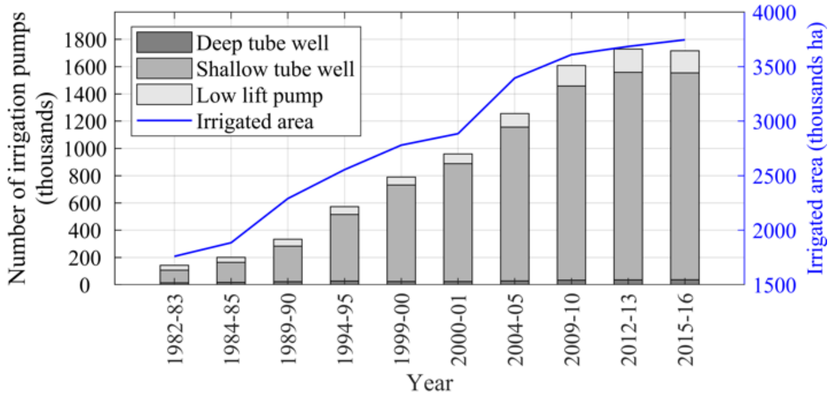

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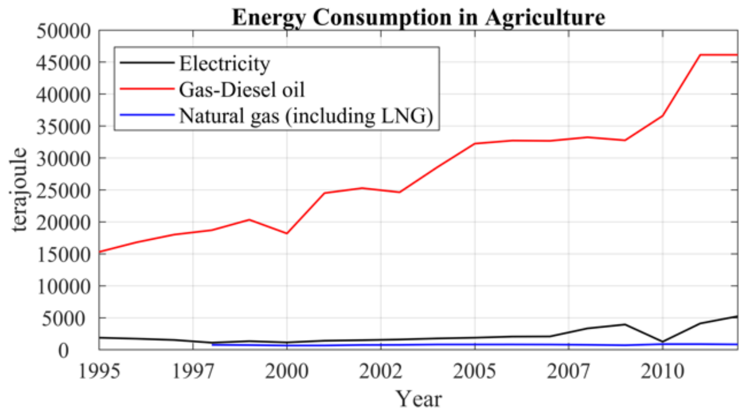

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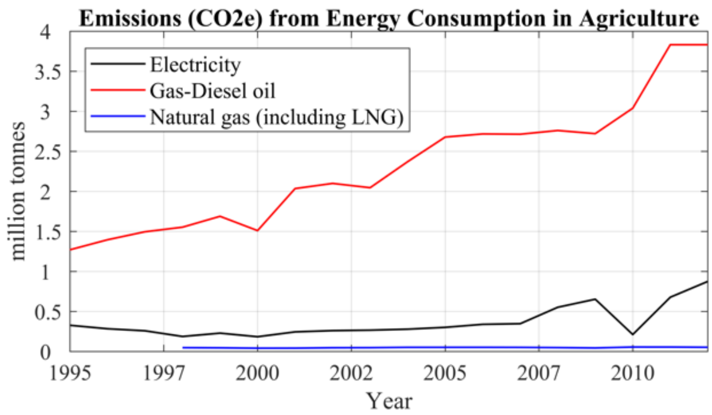

(d)

Fig. 5. Trend in (a) carbon emission from agriculture (1990 to 2017), (b) the number of irrigation pumps and area irrigated (1982-83 to 2015-16), (c) energy consumption in agriculture (1995 to 2012), and (d) carbon emissions from energy consumption in agriculture (1995 to 2012).

4. DISCUSSION

The study analyses the virtual land and water flows through the import of cereal crops in Bangladesh. The study finds that a considerable amount of virtual land and water is being imported in Bangladesh from major trade partner countries, offsetting Bangladesh's GHG emissions at the national level. The country will need additional 2.81 million ha land for cereal crops and additional 12 billion m^3 (blue, green, and grey) water for being food self-sufficient, in turn, increasing the GHG emissions from agricultural activities under the current practices, including mechanization and irrigation. Increasing crop demand in the country will pose extra pressure on local resources to produce more crop per unit resource use. The more resource use (land, water, and energy) under the current practices will finally contribute to the GHG emissions. IPCC [13] lists major mitigation options within agriculture, forestry, and other land use as conserving existing carbon pools in soils or vegetation, enhancing the uptake of carbon in terrestrial reservoirs sequestration), and reducing CO_2 emissions by substitution of biological products for fossil fuels. Demand-side options to reduce carbon emissions within agriculture, forestry, and other land use are lifestyle changes, reducing food wastes and losses, changes in diet, and changes in consumption of wood consumption. Adjusting methods of agricultural land and crop management, livestock, and manure management can reduce the GHG emissions from the agricultural sector.

Mitigation and Low Carbon Development programme T5P5 of Bangladesh Climate Change Strategy and Action Plan 2008 (BCCSAP) [29] aims to increase the productivity of agricultural land and lower GHG emissions from agriculture. One of the major GHG emissions, mainly methane (CH_4), comes from the continuously flooded rice cultivation. The diesel engines used for rice flood irrigation purposes emit CO_2. However, it has been found that alternate wetting and drying, and furrow irrigation systems significantly reduce the water use in rice irrigation systems and increasing productivity [30]. Alternate drying and wetting irrigation technique or furrow irrigation and decreased amount of irrigation water could reduce fuel or energy consumption in rice crop systems, decreasing GHG emissions. Bangladesh INDC, in its possible conditional action-based contributions, targets a decrease in GHG emissions from rice crops by scaling up the rice cultivation using alternate wetting and drying irrigation in 20% rice cropped area [31]. A study by Ali *et al.* [32] in Bangladesh has reported that intermittent irrigation treatment in rice (paddy) fields reduce methane emission by 34 kg/ha as compared to emissions from continuous irrigation treatments (124 kg/ha).

In contrast, it was reported that nitrous oxide emissions from rice (paddy) fields increased to 0.98 kg/ha under intermittent irrigation treatment compared to continuous irrigation treatment (0.55 kg/ha). A study by Kritee *et al.* [27] reported that the Indian subcontinent's nitrous oxide emissions from intermittent irrigation treatment of rice (paddy) fields could be 30-45 times higher than reported under continuous flooding. Therefore, careful consideration should be given for promoting emission-reducing irrigation techniques through scientific research.

A decrease in inorganic fertilizers used in agriculture could also decrease GHG emissions. Bangladesh INDC targets reducing GHG emissions from fertilizers by a 35% increase in the use of organic fertilizers compared to the business as usual (baseline year 2011) scenario [31]. Bangladesh INDC, in its possible conditional action-based contributions in agriculture (non-energy related sector), emphasizes on decreasing agriculture dependence on draft cattle by 50% and increasing the mechanization of agriculture, which may reduce the GHG emissions from agriculture. However, increased fuel consumption in farm mechanization will add to the GHG emissions. Integrated management of land, water, nitrogen, and carbon can reduce GHG emissions from agriculture by 90% [27], mainly from rice cultivation, fertilizers use, and energy consumption for irrigation. Further country-specific potential to reduce agricultural emissions by adopting a life cycle assessment approach is needed.

In Bangladesh Delta Plan 2100 [33], Strategies for Cross-cutting Issues include - agriculture, food security, nutrition and livelihoods, and renewable energy policy measures – aiming to reduce GHG emissions from agriculture. It includes measures to lower emissions from agriculture land, at least 30% energy use from renewable sources by 2041 (about 10% by 2020), use solar energy sources for surface and groundwater irrigation, explores the potential of hydropower or tidal wave energy generation. Changing from fossil fuel to renewable energy use in agriculture and related activities like solar, hydropower, and wind energy could reduce the net emissions from agriculture. In this case, it would be interesting to explore the scenario of Bangladesh being self-sufficient and how much additional land, water, and GHG emissions could be reduced by adopting measures to decrease the emissions from agriculture.

5. SUMMARY AND CONCLUSIONS

The present study finds that 8% of Bangladesh's domestic cereal supply (70% wheat, 17% maize, and 2% rice and related products) was imported through international trade. The annual average virtual cropland harvested area and water imported through the trade of 6.9 million tonnes of the three cereal (excluding products) crops were 2.1 million ha and 14 billion m^3, respectively, during 2014-17. Bangladesh would need additional 2.81 million ha land and 12 billion m^3 water to be cereal self-sufficient, increasing the country's national GHG emission footprint. Enteric fermentation, rice cultivation, manure, and fertilizers were found to be the major sources of GHG emissions. However, energy used in agriculture, mainly for mechanization and irrigation purposes, adds to GHG emissions, and there is potential to use renewable energy sources in an attempt to reduce the GHG emissions. An integrated management of water, energy, and carbon should be considered as one of the strategies to increase the cereal crop production and reduce GHG emissions from agriculture in Bangladesh, and thus contributing to the developmental progress of the country.

Future studies to assess the carbon embedded in crop-wise production against different scenarios of land, water, energy consumption, and other inputs could provide detailed insights into the policy alternatives to reduce the resource use per unit crop production leading to sustainable agriculture. Also, the cascading impact of disasters (natural hazards, conflicts, and war) leading to disruptions in food supply chains (trade) [34, 35, 36] are likely to alter the distribution of virtual land, water, and carbon emission, which could be explored in future studies.

One of the limitations of the present study is the unavailability of data for recent years. The results with increased timespan of cereal trade matrix, food balance sheet, and energy consumption in agriculture until the current year are likely to improve the insights. The present study perspective is from Bangladesh's point of view. GHG emissions from agriculture (mainly production of cereal crops and their export) from the partner countries, which is likely to vary depending on adopted technologies, remain out of the scope of the present study. In addition to the land and water footprints, future studies should incorporate the GHG footprints depending on the data availability.

ACKNOWLEDGEMENT

This research is supported by the UK Research and Innovation Global Challenges Research Fund (UKRI GCRF) Living Deltas Hub (NERC Grant NE/S008926/1, 2019-24).

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