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# Agricultural trade and environment nexus- A case study of rice exports from India

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## Abstract

In recent years there is discussion regarding nexus between agricultural trade and environment and shared responsibility in addressing trade related environmental externalities. In the current study, this nexus is examined focusing on rice exports from India in the recent decade. India's share in quantity of world rice exports was 22.45 per cent on an average in the decade 2010-2019. However, in the same period India's share in water footprint of world rice exports was 28.29 per cent. Further average economic productivity of water in rice exports was 0.24 and 0.22 USD/ $M^3$ in the case of World and India, respectively. The estimated methane emission associated with Indian rice exports ranged between 2.42 to 11.31 per cent of total methane emission from rice production. Totally, 47 countries were involved as top 5 destinations of different types of rice exports from India. Land scarcity, water scarcity, water availability for agriculture, agricultural trade policies in these countries were the underlying factors of the observed rice export pattern of India. Out of these 47 trade partners, in 27 countries, methane emission intensity in paddy was higher than that of India in 2017, but paddy area was lower compared to India. Several national level and international level policy options are available for handling the environmental externalities associated with rice exports from India.

**Keywords:** Paddy, Rice, Trade, Environment, Externality, Agricultural trade, Carbon, Water, Methane, GHG, Emission

## Introduction

Agricultural trade plays an important role in achieving the global food/nutritional security and rural livelihood security. Trade can also serve as a climate change adaptation mechanism in agriculture (Konar *et al., 2016*; Gouel and Laborde, 2021). But Agricultural trade can also affect environment as resource use intensity in production and processing of crops and animal products varies across regions and over time and in turn may contribute to climate change. Hence in recent years, studies focusing on nexus between Agricultural trade and Environment have been carried out quantifying virtual land trade, virtual water trade and trade led Green House Gases (GHG) emissions.

In agriculture, different activities like crop production, livestock production and land use change are the major sources of GHG emissions. Trade in agricultural commodities is leading to specialization in production of some commodities in some countries based on resource availability, technology availability and also sometimes due to trade policy. Thus some countries are producing some agricultural commodities not only for meeting domestic demand but also for meeting export demand. Rice is one such commodity. Davis *et al.,* (2019) reported disproportionately large contribution of rice production to resource use, greenhouse gases, and climate sensitivity relative to its share of *Kharif* cereal calorie production in India. Rice crop is "both a cause and victim of climate change" with significant sustainability implications for India (Prasanna, 2018; Rupal, 2019) as well as at global level (Sporchia *et al.,* 2021). In this backdrop the current study attempts to analyse the dynamics of rice exports from India in the last decade (2010-2019), quantifying rice trade led environmental externalities, understanding underlying factors and identifying some options for addressing these externalities.

## Projections regarding rice production and trade

India is an important rice exporting country contributing 28 per cent of total global rice exports in 2019. OECD-FAO (2020) projected that global rice production will reach 582 million tons in 2029, Asia accounting for an increase of 61 million tons, with highest growth in India. India's share in world rice export is projected as 30 per cent in 2029. OECD-FAO (2020) projected that India will export 14 per cent of its total rice production by 2029. In the calendar year 2021, global rice trade is forecasted as 45.6 million tons against India's rice export forecast of 14 million tons and the global rice trade in the year 2022 as 46.4 million tons (USDA, 2021).

At global level it is projected that rice area will more or less be at 152.45 million ha in 2050 compared to 152.73 million ha in 2010. But a moderate decline in area will be likely in Asia (135.31 to131.51 million ha) and Latin American Countries (6.42 to 5.79 million ha) (Kruseman *et al.,* 2020). The climate change could decrease global rice production by approximately 5%. The decrease in supply would be associated with about an 18-24% higher price (Reardon *et al.,* 2015) indicating a greater challenge in securing rice production than is currently felt. Population growth around 2050 is likely to result in doubling of population in Africa and an increase of 25% in south Asia (United Nations, 2014). In south Asia, urbanization may increase in 2050, but in Africa the opposite may be true with rural areas becoming more densely populated (Swerts *et al.,* 2014, Racki *et al.,* 2014). More than 90% of the global 500 million MT of rice is produced and consumed in Asia (FAO) which is produced from 30% of the total arable land of this region. However, the highest percentage increase in demand for rice is projected for Africa, where rice is becoming a luxury good.

Gouel and Laborde (2021) projected that by the year 2080, with climate change, import volume of rice will increase by 38 % compared to baseline value pertaining to the year 2011. As the traditional rice exporters are tropical countries that will be severely hit by climate change, new exporters emerge *viz*., China, Korea and Japan. Thus the pattern of international trade flows in rice may look extremely different from now because of the effects of climate change (Gouel and Laborde, 2021). According to Sporchia *et al.,* (2021) in view of many constraints to rice production in Africa, African import of rice is expected to gain importance in the next years. African Countries are expected to be the destination of 44% of global rice exports by 2027 compared with 36% in 2016 (FAO, 2019).

## Nexus between agricultural (rice) trade and virtual water trade

Kampman (2007) reported that during 1997-2001, 35 per cent of virtual water flow in interstate trade in India was associated with milled rice trade. They observed largest interregional net virtual water flow from North India to East India and it is in just opposite direction of proposal under interlinking of river projects. According to Ghosh and Bandyopadhyay (2009) by resorting to import of paddy instead of cultivation in Tamil Nadu and Karnataka, both states can increase their water saving.

At global level, Hoekstra and Hung (2005) estimated that**,** during the period 1995-99, virtual water export was 13 per cent of water used for crop production. They observed that U.S, Canada, Thailand, Argentina and India were net virtual water exporters. At global level, approximately eleven per cent of non-renewable groundwater use for irrigation was embedded in international food trade of which two thirds was exported by Pakistan, the USA and India (Carole *et al.,* 2017). Global Ground-Water Depletion (GWD) has increased by 22 per cent in ten years from 240 Km$^3$ in 2000 to 292 Km$^3$ in 2010 (Carole *et al.,* 2017). In case of India, GWD increased from 1.5 Km$^3$ in 2000 to 3 Km$^3$ in 2010. India kept most of its large GWD based crop production for domestic use (only 4% of GWD exported). Individual crops contributing most to global GWD transfers were rice (29%) followed by wheat. Even though most of India's GWD is for domestic consumption, India is still the third-largest GWD exporter primarily via rice and cotton mainly to China (Carole *et al.,* 2017). Rosa *et al*., (2019) observed that about 52 per cent of global irrigation was unsustainable, 15% of it was virtually exported, with an average 18% increase (75 to 88 Km$^3$) between year 2000-2015. India consistently acted as net exporters of Unsustainable Irrigation Water Consumption (UWC) based crops. They reported that India kept 90% of UWC for domestic consumption. India exported unsustainably produced cotton and rice to China and Bangladesh (Rosa *et al.,* 2019).

Yang *et al.,* (2006) observed that during 1997-2001 in the case of rice, volume of virtual water export was more than virtual water import at global level. This indicated that rice production in exporting countries required more water than the production in importing countries. Some studies observed India as net water exporter in agricultural trade in general (Chapagain *et al.,* 2006) and in the case of rice trade in particular (Sree Vidhya and Elango, 2019). Chouchane *et al.,* (2018) projected that global international trade in staple crops will increase by a factor of 1.4-1.8 towards 2050 (compared to the average in 2001-2010) in order to meet the staple food needs of the 42 most water-scarce countries in the world as a result of population growth. They observed continuous increase in net import of staple crops per capita with decreasing water availability per capita (1961-70 to 2001-10). However, India, Pakistan and Sri Lanka were the exceptions to the general pattern with decreasing net staple food imports. India and Pakistan shifted to become net exporters despite their increasing water scarcity and are expected to become net importers of staple crops by 2050 (Chouchane *et al.,* 2018).

**Nexus between (Cereal) Trade and GHG transfer**

Shapiro (2016) has estimated that the opening of border raises global $CO_2$ emission in the order of 5% compared to a self sufficient situation without any international trade. On the other hand, Nguyen (2020) using the panel data of 89 economies from 1995-2012, examined major drivers of agricultural emission. They observed that trade openness and Foreign Direct Investment (FDI) inflows have significantly negative effects on GHG emission from agriculture in the long run.

Sporchia *et al.,* (2021) used Physical Trade Analysis (PTA) based on Material Flow Analysis (MFA) to analyse three most relevant environmental stressors associated with global rice production *viz*., water, land-use and methane emission in 167 countries during the period 2000-2016 (17 years). Total water use grew by 8% (from 892 to 962 Gm$^3$) and land use and methane emission increased by 7% (154 to 165 Mha and from 23 to 25 M tons, respectively). Green and blue water use increased by 9% and 2% passing from 689 to 753 Gm$^3$ and from 204 to 209 Gm$^3$, respectively. Share of rice trade in the selected stressors was 6%. Despite the general growth, large amount of land, water and methane emission were saved due to improvement in rice production efficiency. Intensity of global rice production resulted in saving of 240 Gm$^3$ water, 40 m ha of land and 31 K tons of methane. But the saving was not sufficient to reduce the increase. The savings were concentrated in some areas (South East Asia, Southern America). India saved 77 Gm$^3$ of water (of which 58 green and 19 blue), 14 M ha of land and 6 Tg of methane). The share of virtual water, land and emission grew from 3.8 to 6.2% for total water, 3.5 to 5.7% for land and from 4.4% to 5.7% methane emission from 2000 to 2016. Substantial part of the Asiatic production of rice was driven by African demand (Benin, Cote D'Ivoire, Kenya, Senegal, Cameroon and Mozambique). Benin, the second largest importer of rice after China, was among the largest virtual water, land and emission importer. In 2016, Asia was the largest import region for virtual water, land and emission (43,44 and 40%) followed by Africa, Europe and North America. If yield of rice at global level improved by 0.5 tons/ha, it would result in a global reduction of about 10% of rice related environmental toll for the same amount of rice production.

## Methodology

Most of the past studies on trade and environment nexus in the context of India were with limited focus *i.e.,* they estimated aggregate virtual water (resource) trade and water (resource) saving associated with different commodities trade. In the current study besides estimation of virtual water trade, economic water productivity and efficiency in virtual water trade associated with rice trade are analysed. While analysing these issues, current study focused on different types of rice exported from India *viz*., Rice in the husk (Paddy), Husked brown rice, Semi-milled/wholly milled rice and Broken Rice contrary to past studies which focussed on total (aggregate) rice exports. These are referred as paddy, brown rice, milled rice and broken rice, respectively in subsequent sections of this paper. GHG emission associated with rice trade also estimated following IPCC (2006) method. Finally, the underlying rationale behind rice exports and options (technologies, policies) for addressing sustainability issues associated with Indian rice trade are discussed.

Data on rice exports for the years 2009-10 to 2019-20 was collected from APEDA (Agricultural and Processed Foods Export Development Authority) website. Data on different types of rice exports was collected from COMTRADE website. Water Foot print estimates of Mekonnen and Hoekstra (2010) were used in Economic water productivity computations. Data on Renewable Water Resource Available Per capita (RWRAP) and share of Agricultural Water Withdrawal in Total Water Withdrawal (AWWTWW) of different countries in the year 2017, was collected from FAOSTAT database. Data on arable land available per capita, rice area harvested, and Emission Intensity of rice cultivation in different countries was collected from FAOSTAT database. Simple descriptive statistics have been used in analysing the data.

## Results and Discussion

Rice exports from India increased from 2.16 million tons in 2009-10 to 9.49 million tons in 2019-20 (**Figure 1**). The share of rice exports in total rice production in India ranged between 2.42 per cent to 11.31 per cent in different years of the last decade (**Figure 2**). Average quantity of rice exports from India from 2009-10 to 2019-20 stood at 9.10 million tons accounting for 8.56 per cent of average rice production. In 2019 Global trade in rice fell due to reduced Asian import demand in particular from Bangladesh, China and Indonesia (OECD-FAO, 2020). Accordingly, rice exports from India also declined to 9.49 million tons in 2019-20, compared to 11.95 million tons in 2018-19, further the decline was confined to non-basmati rice. In the following section, rice exports and water productivity details are discussed focusing on (i) four types of rice exports from India during the calendar years 2010-2019 and (ii) basmati and non-basmati rice exports during 2009-10 to 2019-20.

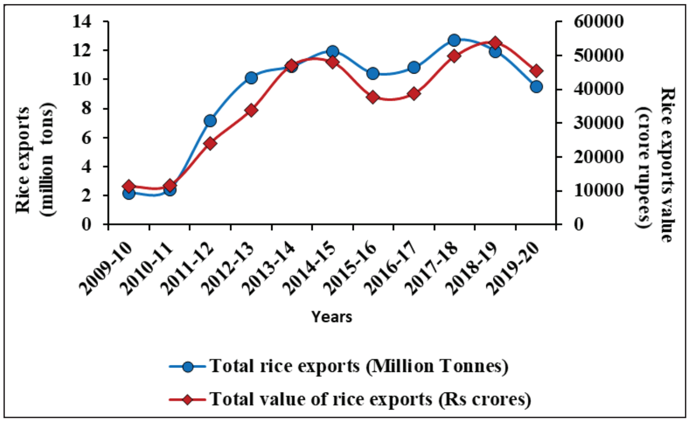

**Figure 1. India's rice exports quantity and value**

Basmati rice accounted for almost 6% of the total rice produced in India (Kumar, 2019). The share of basmati rice in total quantity of rice exported from India declined from 93.53 per cent in 2009-10 to 46.94 per cent in 2019-20 (**Figure 2**). This is consequence of policy of removal of ban on non-basmati rice exports during later part of the year 2011. However, in absolute terms, quantity of basmati rice exports from India doubled in 2019-20 compared to 2009-10. In all the years under consideration, unit value realized from basmati rice exports ranged between 2.06 to

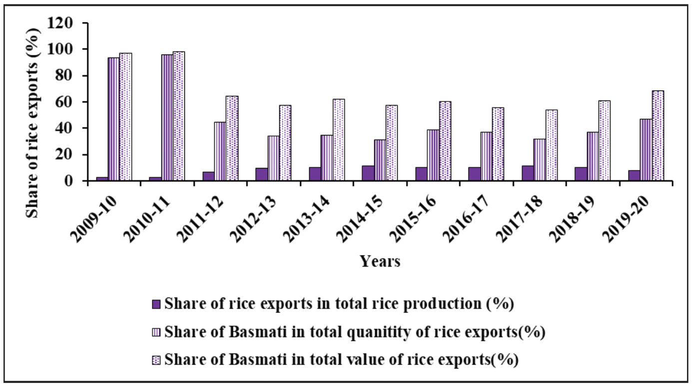

**Figure 2. Share of rice exports**

3.13 times of unit price realized from non-basmati rice exports (**Table.1**). Further ratio of non-basmati rice export price to domestic MSP ranged from 1.04 to 1.65 with lowest value in 2019-20. But Kumar (2019) reported lower export price of rice compared to wholesale price and squeeze in margin of farmers.

**Table 1. Ratio of rice export price to MSP in India**

| Year | Ratio of unit value of exports of Basmati and non-basmati rice | Ratio of Basmati export price to MSP of rice | Ratio of Non-basmati export price to MSP of rice |
|---|---|---|---|
| 2009-10 | 2.06 | 3.39 | 1.65 |
| 2010-11 | 2.12 | 3.22 | 1.52 |
| 2011-12 | 2.25 | 2.98 | 1.33 |
| 2012-13 | 2.60 | 2.96 | 1.14 |
| 2013-14 | 3.13 | 3.93 | 1.25 |
| 2014-15 | 3.02 | 3.62 | 1.20 |
| 2015-16 | 2.37 | 2.63 | 1.11 |
| 2016-17 | 2.15 | 2.43 | 1.13 |
| 2017-18 | 2.49 | 2.82 | 1.13 |
| 2018-19 | 2.68 | 2.80 | 1.05 |
| 2019-20 | 2.44 | 2.53 | 1.04 |

MSP = Minimum support price

India's share in quantity of world exports of paddy ranged between 0.62 to 9.70 per cent across different years in the decade 2010-2019 (**Table 2**). India's share in world rice exports quantity ranged between 9.10 to 31.22 per cent in case of milled rice, 0.01 to 5.13 per cent in the case of brown rice and 0.01 to 27.88 per cent in the case of broken rice. On average, the share of India in quantity of world rice exports was 6.64, 1.01, 25.97 and 17.88 per cent in paddy, brown rice, milled rice and broken rice, respectively. On the other hand, average share of India in value of World rice exports was 6.86, 0.82, 29.58, and 14.26 per cent in paddy, brown rice, milled rice and broken rice, respectively. Thus India's share in average world exports of the four rice forms (put together) was 22.45 and 25.84 per cent in quantity and value, respectively (**Table 2**). The unit value realized from world rice exports was more than unit value realized in rice exports from India in 2, 6, and 9 years in the case of rice in husk (paddy), brown rice, and broken rice, respectively (**Figure 3**). This indicates fluctuating competitiveness of India's' rice exports across four types of rice products. In all the ten calendar years (2010 to 2019), milled rice share in total Indian rice export quantity (ranging between 86 to 99 per cent) and value (ranging between 93 to 99 per cent) was the highest (**Table 3**). It was followed by broken rice and rice in the husk *i.e.,* paddy (except in year 2010). Further only in the case of milled rice, share of value of exports was more than share of quantity of exports.

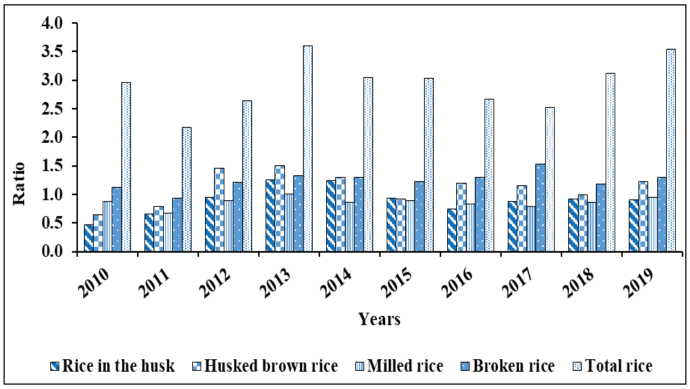

**Figure 3. Ratio of unit price of world rice export to India's rice export**

**Table.2 Rice exports and prices at global level and from India during 2010-2019**

| Parameters | World | | | India | | | India's share in | |
|---|---|---|---|---|---|---|---|---|
| | Trade Qty (million tons) | Trade Value (Million US$) | Unit value (US$/ton) | Trade Qty (million tons) | Trade Value (Million US$) | Unit value (US$/ ton) | Quantity of world rice export (%) | World rice export Trade Value (%) |
| **Rice in the husk (Paddy/rough)** | | | | | | | | |
| Minimum | 2.01 | 710.67 | 325.63 | 0.02 | 13.20 | 340.83 | 0.62 | 1.31 |
| Maximum | 3.10 | 1072.49 | 430.92 | 0.25 | 90.73 | 788.14 | 9.70 | 10.46 |
| Average | 2.55 | 918.74 | 360.81 | 0.17 | 63.07 | 372.88 | 6.64 | 6.86 |
| SD | 0.30 | 119.99 | 41.76 | 0.09 | 27.40 | 149.47 | 3.19 | 2.95 |
| **Husked (brown) rice** | | | | | | | | |
| Minimum | 1.53 | 898.49 | 474.65 | 0.0001 | 0.09 | 356.39 | 0.01 | 0.01 |
| Maximum | 4.44 | 2107.17 | 687.96 | 0.11 | 45.63 | 753.16 | 5.13 | 3.40 |
| Average | 2.58 | 1487.62 | 576.47 | 0.03 | 12.21 | 469.17 | 1.01 | 0.82 |
| SD | 0.84 | 361.78 | 75.32 | 0.03 | 13.79 | 134.48 | 1.54 | 1.02 |
| **Semi-milled/wholly milled rice, whether/not polished/glazed** | | | | | | | | |
| Minimum | 27.34 | 16714.28 | 529.12 | 2.49 | 2282.45 | 558.28 | 9.10 | 13.66 |
| Maximum | 36.41 | 22158.44 | 665.88 | 10.72 | 7754.82 | 916.76 | 31.22 | 35.98 |
| Average | 32.89 | 19740.15 | 600.19 | 8.54 | 5838.15 | 683.51 | 25.97 | 29.58 |
| SD | 2.83 | 1786.54 | 48.41 | 2.69 | 1683.55 | 112.72 | 7.23 | 7.11 |
| **Broken Rice** | | | | | | | | |
| Minimum | 2.97 | 1150.55 | 341.31 | 0.0002 | 0.07 | 278.05 | 0.01 | 0.01 |
| Maximum | 5.69 | 1942.98 | 455.86 | 1.3676 | 421.24 | 414.71 | 27.88 | 23.73 |
| Average | 4.37 | 1652.09 | 377.85 | 0.78 | 235.61 | 301.47 | 17.88 | 14.26 |
| SD | 0.90 | 230.52 | 39.12 | 0.46 | 140.69 | 39.15 | 9.24 | 7.69 |
| **Total Rice** | | | | | | | | |
| Minimum | 34.55 | 19769.85 | 502.61 | 2.51 | 2295.81 | 536.54 | 7.25 | 11.61 |
| Maximum | 48.72 | 26439.88 | 627.61 | 12.12 | 8169.52 | 915.86 | 27.81 | 31.79 |
| Average | 42.39 | 23798.61 | 561.43 | 9.52 | 6149.05 | 646.04 | 22.45 | 25.84 |
| SD | 4.23 | 2132.44 | 45.63 | 3.17 | 1819.31 | 119.17 | 6.46 | 6.28 |

**Table 3. Share of different types of rice in total India's rice exports quantity and value (%)**

| Year | Paddy quantity | Brown Rice quantity | Milled rice quantity | Broken rice quantity | Paddy value | Brown Rice value | Milled rice value | Broken rice value |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.67 | 0.00 | 99.32 | 0.01 | 0.58 | 0.00 | 99.42 | 0.00 |
| 2011 | 0.77 | 0.05 | 94.83 | 4.34 | 0.58 | 0.04 | 97.79 | 1.59 |
| 2012 | 2.38 | 1.07 | 88.27 | 8.28 | 1.40 | 0.74 | 93.18 | 4.67 |
| 2013 | 2.12 | 0.22 | 88.74 | 8.92 | 1.01 | 0.16 | 94.92 | 3.90 |
| 2014 | 1.63 | 0.51 | 89.52 | 8.34 | 0.79 | 0.33 | 95.35 | 3.54 |
| 2015 | 1.82 | 0.14 | 87.65 | 10.40 | 1.14 | 0.14 | 93.68 | 5.04 |
| 2016 | 1.05 | 0.15 | 91.44 | 7.36 | 0.89 | 0.15 | 95.15 | 3.82 |
| 2017 | 1.38 | 0.09 | 88.45 | 10.07 | 0.88 | 0.12 | 93.77 | 5.23 |
| 2018 | 2.08 | 0.09 | 86.11 | 11.72 | 1.24 | 0.10 | 92.93 | 5.73 |
| 2019 | 2.52 | 0.10 | 94.21 | 3.17 | 1.32 | 0.05 | 97.30 | 1.33 |
| Average | 1.78 | 0.27 | 89.74 | 8.21 | 1.03 | 0.20 | 94.94 | 3.83 |

**Dynamics of rice exports from India**

Dynamics of Indian rice exports was analysed and found that the share of top 5 importing countries of rice from India was above 50 per cent in the case of paddy, brown rice and broken rice quantity in all 10 years under consideration **(Table 4)**. Only in the case of milled rice quantity, the top 5 countries share was below 50 per cent in 7 out of 10 years considered. There was no consistent pattern in top 5 importers share in value of rice import from India. When compared to the year 2010, in 2019, top 5 countries share increased in the case of paddy quantity, but declined in the case of brown rice, milled rice and broken rice. Over the decade as top 5 importers, totally 17 countries were involved in paddy imports from India. The corresponding number of countries was 21, 12 and 18 in case of brown rice, milled rice and broken rice, respectively against maximum possible value of 50 countries (10*5). Thus in the case of milled rice, less dynamics (in terms of number of countries involved as top 5 importers) is coupled with declining share of top 5 countries imported quantity. Dynamics of Indian Rice exports in terms of Basmati vs non-basmati also was analysed (**Table 4**). In all the ten years share of top 5 importers in quantity of rice import was above 50 per cent in case of basmati

**Table 4. Share of top five destination countries in India's rice exports**

| year | Rice in husk | | Brown rice | | Milled Rice | | Broken Rice | |
|---|---|---|---|---|---|---|---|---|
| | **Quantity (%)** | **Trade Value (%)** | **Quantity (%)** | **Trade Value (%)** | **Quantity (%)** | **Trade Value (%)** | **Quantity (%)** | **Trade Value (%)** |
| 2010 | 94 | 94 | 99 | 99 | 85 | 85 | 96 | 96 |
| 2011 | 94 | 94 | 59 | 52 | 60 | 67 | 87 | 82 |
| 2012 | 79 | 55 | 98 | 97 | 44 | 49 | 84 | 83 |
| 2013 | 79 | 64 | 93 | 91 | 50 | 58 | 86 | 85 |
| 2014 | 96 | 89 | 95 | 94 | 41 | 46 | 86 | 85 |
| 2015 | 97 | 90 | 70 | 69 | 40 | 46 | 88 | 87 |
| 2016 | 97 | 92 | 74 | 74 | 43 | 49 | 87 | 86 |
| 2017 | 99 | 95 | 64 | 65 | 39 | 43 | 87 | 86 |
| 2018 | 99 | 96 | 78 | 81 | 41 | 47 | 84 | 83 |
| 2019 | 100 | 99 | 93 | 86 | 44 | 54 | 76 | 72 |
| | **Number of countries involved as top 5 countries in the 10 years** | | | | | | | |
| | **17** | | **21** | | **12** | | **18** | |
| | **Basmati rice** | | **Non-basmati** | | | | | |
| | **Quantity (%)** | **Trade Value (%)** | **Quantity (%)** | **Trade Value (%)** | | | | |
| 2010-11 | 84 | 83 | 74 | 66 | | | | |
| 2011-12 | 71 | 71 | 47 | 46 | | | | |
| 2012-13 | 69 | 69 | 49 | 46 | | | | |
| 2013-14 | 75 | 75 | 46 | 42 | | | | |
| 2014-15 | 70 | 69 | 47 | 43 | | | | |
| 2015-16 | 71 | 70 | 45 | 40 | | | | |
| 2016-17 | 69 | 68 | 43 | 39 | | | | |
| 2017-18 | 67 | 67 | 53 | 50 | | | | |
| 2018-19 | 73 | 72 | 41 | 37 | | | | |
| 2019-20 | 71 | 70 | 43 | 40 | | | | |
| | **Number of countries involved as top 5 countries in the 10 years** | | | | | | | |
| | 7 | | 14 | | | | | |

rice. In case of non-basmati rice, only in 2 years' top 5 importers share was above 50 per cent. But, in the case of both basmati and non-basmati rice, top 5 importers share declined in 2019-20 compared to 2010-11. Across the ten years, 7 countries were involved as top 5 importers in the case of basmati against 14 countries in the case of non-basmati rice.

## Economic water productivity and virtual water trade from India through rice exports

Mekonnen and Hoekstra (2010) estimated water footprint (cubic meter of water per unit of output) of different crops and crop products for the period 1996 to 2005 for 113 countries. In the case of rice and rice products, India stood at 50th place indicating 49 countries were above it with lower Water Footprint (WF). The WF for selected four rice types/products in the case of India as well at global level indicated that the WF of Indian rice products is more than global level WF by 1.24 times (**Table 5**). Using these WF metrics, total WF of Indian rice exports and global rice exports during 2010-2019 are computed and presented in **Table 6**. On average India's share in virtual water trade of world rice exports was 8.22, 1.25, 32.13 and 22.12 per cent in the case of paddy (rice in husk), brown rice, milled rice and broken rice, respectively (**Figure 4**). This is more than corresponding share in quantity of rice exports as well as share in value

**Table.5 Water footprint of different rice types**

| Product description | Water foot print ($M^3$/Ton) | |
|---|---|---|
| | Global average | India |
| Rice in the husk (paddy or rough) | 1673 | 2070 |
| Rice, husked (brown) | 2172 | 2688 |
| Rice, semi-milled or wholly milled, whether or not polished or glazed | 2414 | 2986 |
| Rice, broken | 2497 | 3089 |

**Source :** Mekonnen, M.M. and Hoekstra, A.Y. (2010) The green, blue and grey water footprint of crops and derived crop products.

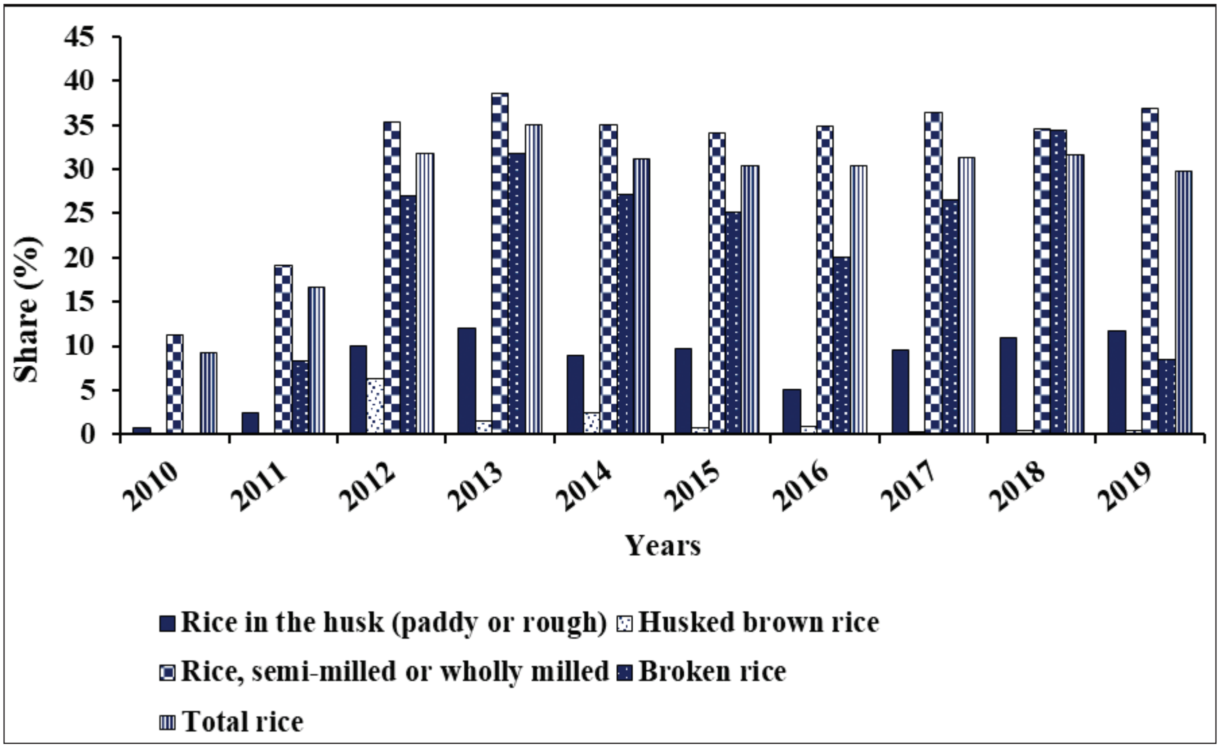

**Figure 4. India's share in water footprint of rice exports at global level**

of rice exports (**Table 2**). This indicates lower water use efficiency of Indian rice exports. Mekonnen and Hoekstra (2014) showed that small WFs are not inherent to high income countries or humid regions and the large WFs are not intrinsically connected to low income countries or arid regions. Hence, there is possibility to decrease WF through proper water management (like System of Rice Intensification (SRI), Alternate Wetting and Drying (AWD) etc., and through adoption of water saving technologies (like drip and sprinkler irrigation) in India also.

There are some criticisms regarding the concept of WF. Water Footprint considers only the volume of water used in production and hence not sufficient indicators of the benefits or cost of water use in any setting (Wichelns, 2015). Hence, to overcome this deficiency (at least partially) economic water productivity of Indian rice exports is computed in this study and contrasted with economic water productivity of rice exports at global level (**Table 6**). Economic water productivity of Indian rice exports in 2010-2019 decade ranged between 0.16 to 0.38 US$ per cubic meter in the case of paddy (Husked rice). The corresponding ranges were 0.13 to 0.28, 0.19 to 0.31 and 0.09 to 0.13 US$ per cubic meter in the case of husked brown rice, milled rice, and broken rice, respectively. In the decade under focus, maximum value of economic water productivity across all four types of rice exported was observed in the year 2010. However, across the four types of rice exported, the year in which minimal economic productivity observed was not the same year. In the period under focus the economic water productivity of rice exports at global level was higher than Indian level, in 7, 8,8,10 years in the case of paddy, brown rice, milled rice and broken rice, respectively (**Figure 5**). This once again indicates lower water use efficiency of rice exported from India.

**Table.6 Economic water productivity in rice exports during 2010-2019**

| Parameters | World | | India | |
|---|---|---|---|---|
| | **Total water print (Gm3)** | **Economic water productivity (Us $/m3 )** | **Total water print (Gm3)** | **Economic water productivity (Us $/m3 )** |
| **Rice in the husk (paddy or rough)** | | | | |
| Minimum | 3.37 | 0.19 | 0.03 | 0.16 |
| Maximum | 5.19 | 0.26 | 0.52 | 0.38 |
| Average | 4.26 | 0.22 | 0.35 | 0.18 |
| **Husked (brown) rice** | | | | |
| Minimum | 3.31 | 0.22 | 0.0003 | 0.13 |
| Maximum | 9.64 | 0.32 | 0.30 | 0.28 |
| Average | 5.61 | 0.27 | 0.07 | 0.17 |
| **Rice, semi-milled or wholly milled** | | | | |
| Minimum | 66.01 | 0.22 | 7.44 | 0.19 |
| Maximum | 87.90 | 0.28 | 32.02 | 0.31 |
| Average | 79.39 | 0.25 | 25.51 | 0.23 |
| **Broken rice** | | | | |
| Minimum | 7.42 | 0.14 | 0.0005 | 0.09 |
| Maximum | 14.21 | 0.18 | 4.22 | 0.13 |
| Average | 10.92 | 0.15 | 2.41 | 0.10 |
| **Total Rice** | | | | |
| Minimum | 81.28 | 0.21 | 7.47 | 0.18 |
| Maximum | 115.39 | 0.27 | 36.17 | 0.31 |
| Average | 100.17 | 0.24 | 28.34 | 0.22 |

* water productivity average is weighted average

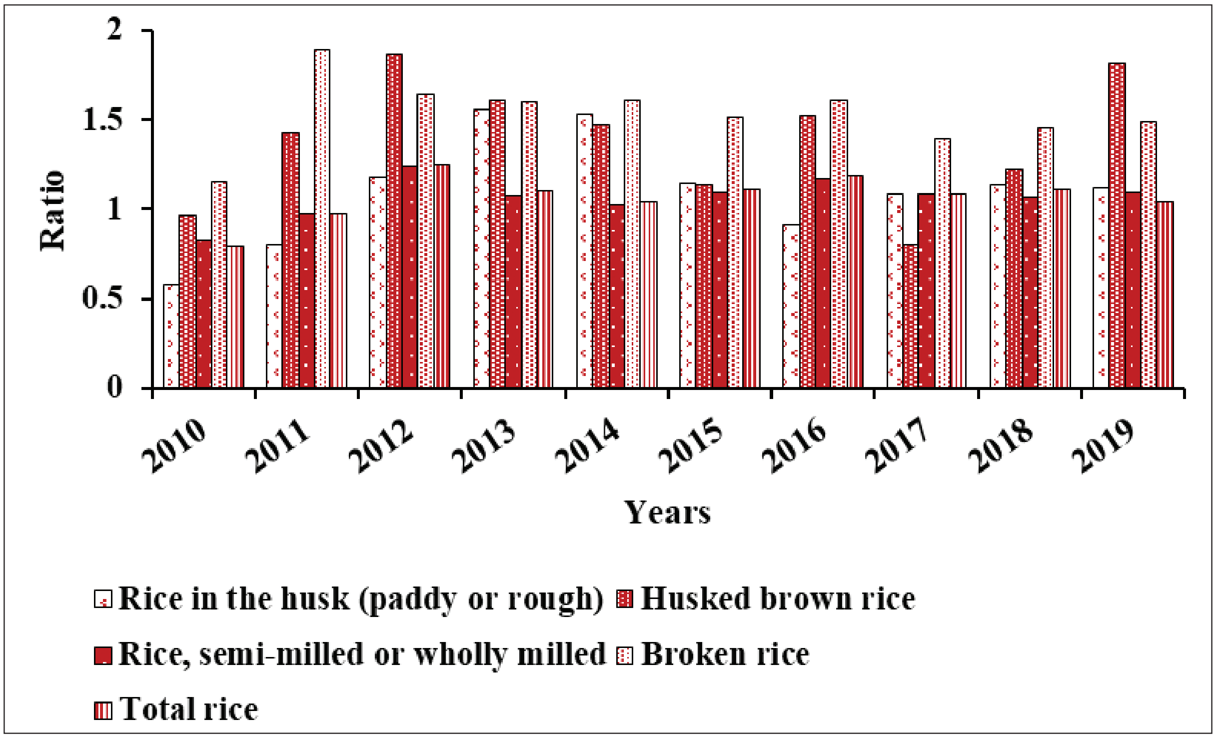

**Figure 5. Ratio of economic water productivity of world to India in rice exports**

Economic water productivity was also analysed for basmati and non-basmati rice exports separately using a water foot print of 4545 and 2986 $m^3$ per ton of rice respectively. Across the years (2009-10 to 2019-20) economic water productivity of Basmati rice exports ranged between 10.72 to 17.17 Rs per cubic meter of water against 7.24 to 9.54 Rs per cubic meter of water in non-basmati rice exports **(Table 7).** Economic water productivity of total (basmati and non-basmati) rice exports ranged between 9.16 to 12.86 Rs per cubic meter of water. In all the years under consideration, ratio of economic water productivity of basmati rice exports to Non-basmati rice exports from India was greater than one but this was lower than the ratio of unit value of basmati rice exports to unit value of non-basmati rice exports. Economic water productivity of rice in domestic sale at Minimum Support Price (MSP) ranged between 5.07 to 9.21 Rs per cubic meter of water. Hence the margin in total rice exports in terms of economic water productivity ranged between 2.59 to 6.42 across the years (2009-10 to 2019-20). However, the margin in case of non-basmati rice exports alone in terms of economic water productivity ranged between 0.33 (in 2019-20) to 3.44 (in 2009-10) Rs per cubic meter of water. These results are in line with Gawel and Bernsen (2013) argument that a water scarce but land rich country will export water intensive commodities only as long as the scarcity value of domestic water as an input in agriculture remains lower than the scarcity value of water in the importing country.

Gawel and Bernsen (2013) indicated that a water scarce country may have higher water productivity in certain crops than in a water rich country. India exported paddy to 17 countries as top 5 destinations in the decade 2010-2019. In this case, out of 50 instances (*i.e.,* top 5 countries in 10 years) in 29 instances (*i.e.,* 58 per cent instances) paddy export was to countries with lower water foot print (*i.e.,* countries with higher water use efficiency compared to India). In case of husked brown rice, milled rice, and broken rice such instances of exporting to countries with lower water foot print was 56, 22 and 26 per cent, respectively.

Novo *et al.,* (2009) observed that Spanish international trade with grains during 1997-2005 as net virtual water importer was consistent with *relative water scarcity,*

**Table.7 Economic water productivity in basmati and non-basmati rice exports (Rs/M$^3$)**

| Year | Economic water productivity of basmati rice | Economic water productivity of non-basmati rice | Economic water productivity of total rice | Ratio of economic water productivity of basmati rice to non-basmati rice | Domestic water productivity at MSP | Margin in exports of basmati rice | Margin in exports of non-basmati rice | Margin in exports of total rice |
|---|---|---|---|---|---|---|---|---|
| 2009-10 | 11.88 | 8.77 | 11.74 | 1.36 | 5.33 | 6.55 | 3.44 | 6.42 |
| 2010-11 | 10.72 | 7.69 | 10.64 | 1.39 | 5.07 | 5.65 | 2.62 | 5.56 |
| 2011-12 | 10.73 | 7.26 | 9.16 | 1.48 | 5.48 | 5.24 | 1.78 | 3.68 |
| 2012-13 | 12.34 | 7.24 | 9.49 | 1.71 | 6.34 | 6 | 0.89 | 3.14 |
| 2013-14 | 17.17 | 8.34 | 12.26 | 2.06 | 6.65 | 10.52 | 1.69 | 5.61 |
| 2014-15 | 16.4 | 8.28 | 11.58 | 1.98 | 6.9 | 9.5 | 1.38 | 4.68 |
| 2015-16 | 12.36 | 7.93 | 10.1 | 1.56 | 7.15 | 5.2 | 0.77 | 2.95 |
| 2016-17 | 11.88 | 8.42 | 10.05 | 1.41 | 7.46 | 4.43 | 0.96 | 2.59 |
| 2017-18 | 14.58 | 8.89 | 11.26 | 1.64 | 7.86 | 6.71 | 1.03 | 3.4 |
| 2018-19 | 16.35 | 9.29 | 12.62 | 1.76 | 8.88 | 7.47 | 0.41 | 3.74 |
| 2019-20 | 15.32 | 9.54 | 12.86 | 1.61 | 9.21 | 6.11 | 0.33 | 3.65 |

as net imports increased in dry years. Debaere (2014) observed that water is indeed a source of comparative advantage and that countries that have more water available per capita tend to export more water-intensive goods. But contrary observations were made by Mohammad *et al.,* (2020), and Chen *et al.,* (2021). Yang *et al.,* (2003) examining the relationship between water scarcity and induced cereal import, estimated a water resource threshold with respect to cereal import as 1500 m$^3$/capita. According to them, below the threshold, the demand for cereal import increases exponentially with decreasing water resources. They predicted that in India, renewable fresh water falls below the threshold by the year 2030. But by 2017 itself renewable water resource available per capita in India fell to 1427 m$^3$. Thus *India is not a water rich country,* but still India is exporting rice. According to Key and Runsten, (1999) contract farming, together with lack of optimal water management policies also sometimes lead to situation wherein water scarce countries end up exporting virtual water to more productive developed nations.

Gawel and Bernsen (2013) argued that realigning virtual water trade flows according to notions of global water use efficiency is contradictory to economic efficiency concepts. Debaere (2014) opined that measure of country's available renewable freshwater per capita should be a better proxy of the true (opportunity) cost of water than the actual water prices consumers and producers pay. Countries comparative advantage hinges on both the variation of factor intensities among sectors and on the relative factor abundances across countries (Debaere, 2014; Fracasso, 2014). Keeping this observation in view, analysis was carried out focussing on India's top 5 rice export destination countries. Totally 47 countries were top 5 destinations in the period 2010-2019 across 4 types of rice/rice product exports. These 47 countries were categorized into 4 categories along two dimensions *viz.*, Renewable Water Resource Available Per capita (RWRAP) in 2017 and share of Agricultural Water Withdrawal in Total Water Withdrawal (AWWTWW) in 2017, keeping India as a reference country. In case of India, renewable water resource available per capita and share of agricultural water withdrawal in total water withdrawal in the year 2017 was 1427 m$^3$ and 90.41 per cent, respectively (FAO-AQUASTAT).

Out of 47 countries under focus, in 32 countries (*i.e.,* 68% of countries) RWRAP was more than India's RWRAP (**Table 8**). Out of these 32 countries, in 8 countries AWWTWW was more than India's AWWTWW (first quadrangle). Thus in these 8 countries water value may be more in other crops compared to rice. In the rest 24 countries, economic water scarcity (with higher value of water in other sectors) might led to lower AWWTWW (second quadrangle). Nepal and Vietnam (which were consistently in the list of top 5 importers of paddy), Iran (which was consistently in the list of top 5 importer of milled rice) and Senegal (which was consistently in the list of top 5 importer of broken rice) were having both RWRAP and AWWTWW greater than India. United Kingdom (which was consistently in the list of top 5 importer of brown rice) was having RWRAP higher than India, but AWWTWW lower than India. In Bangladesh which was having RWRAP higher than India, but AWWTWW lower than India, three fourths of freshwater withdrawal was for paddy irrigation. But nearly 39 per cent of water was over irrigated in paddy (Islam *et al.,* 2021).

Out of 15 countries in which RWRAP was less than that of RWARAP of India, in 3 countries (Ethiopia, Pakistan and Yemen) AWWTWW was more than AWWTWW of India (Third quadrangle). In these 3 countries too, water value may be more in other crops compared to rice. In case of Yemen, it is reported that a policy of subsidizing import of grains together with promoting high value crop cultivation was pursued (Ward, 2000). Thus, only in 12 out of 47 (top 5) destinations of Indian rice export, *i.e.,* 26 % countries, both RWRAP and AWWTWW was below that of India. United Arab Emirates (a consistent importer of brown rice and milled rice from India) and Saudi Arabia (a consistent importer of milled rice from India) were the countries appearing in the 12 countries group. Seven countries which were involved as top 5 basmati rice importers from India, were spread across all four quadrangles with maximum number (3 *i.e.,* Kuwait, Saudi Arabia and United Arab Emirates) in quadrangle four (**Table 8**). This is quite natural phenomenon as Basmati rice is a special type rice produced in India, wherein consumer preference is the underlying driver of trade. However, 14 countries involved as top 5 importers of non-basmati rice from India were also spread across all four quadrangles with maximum number of countries in quadrangle 2.

Besides water availability, arable land availability/scarcity may also drive agri-food trade. In case of Japan (a water rich country) it is scarcity of land that shaped country's food import policies (Oki and Kanae, 2004). Kumar and Singh (2005) observed that virtual water exports increased with increase in gross cropped area because (i) access to arable land increases the ability to utilize available blue water for irrigation and (ii) increasing access to arable land improves the access to water held in the soil profile as "free good". In the current context, out of 47 countries (which were top 5 importers of four different rice types from India) in 25 (*i.e* in 53%) countries, per capita arable land available was lower than that of India (0.1181ha). Out of these 25 countries, 14 countries were with RWRAP greater than RWRAP of India. Overall out of 47 export destinations of rice exports from India under consideration, only 11 export destination countries were both water scarce and land scarce countries (compared to India). These observations are in line with previous reports that not all countries import food because of water scarcity (Yang *et al.,* 2003; Yang *et al.,* 2006; Verma *et al.,* 2009; Gawel and Bernsen, 2013)**.** Chen *et al.,* (2021) observed that most countries with low per capita land were net importers of embodied land while many countries with extreme water shortage were net exporters of virtual water. Thus global trade encouraged optimal distribution of land resources but exacerbated the uneven distribution of water resources. Mohammad *et al.,* (2020) showed that less developed countries that lack capital may end up specializing in water-intensive agricultural goods, even if their water resources are not plentiful.

**Table.8 Water resource availability, water use in agriculture and arable land availability in India’s top five rice export destination countries in 2017**

| | Renewable water resource per capita >India | | | | Renewable water resource per capita <India | | | |
|---|---|---|---|---|---|---|---|---|
| | **Country** | **Total renewable water resources per capita (m3/ inhabitant/ year)** | **Agricultural water withdrawal as % of total water withdrawal (%)** | **Arable land (hectares per person)** | **Country** | **Total renewable water resources per capita (m3/ inhabitant/ year)** | **Agricultural water withdrawal as % of total water withdrawal (%)** | **Arable land (hectares per person)** |
| | India | 1427 | 90.41 | 0.12 | | | | |
| | **First Quadrangle** | | | | **Third Quadrangle** | | | |
| **Agricultural water withdrawal % of total water withdrawal >India** | Bhutan | 104619 | 94.08 | 0.14 | Ethiopia | 1147 | 91.84 | 0.15 |
| | Iran | 1699 | 92.18 | 0.18 | Pakistan | 1187 | 93.98 | 0.15 |
| | Iraq | 2393 | 91.49 | 0.14 | Yemen | 75 | 90.74 | 0.05 |
| | Madagascar | 13179 | 95.89 | 0.14 | | | | |
| | Nepal | 7607 | 98.14 | 0.08 | | | | |
| | Senegal | 2527 | 92.98 | 0.21 | | | | |
| | Timor-Leste | 6608 | 91.38 | 0.13 | | | | |
| | Viet Nam | 9346 | 94.78 | 0.07 | | | | |
| | **Second quadrangle** | | | | **Fourth Quadrangle** | | | |
| **Agricultural water withdrawal % of total water withdrawal <India** | Australia | 20013 | 63.43 | 1.9 | Bahrain | 78 | 33.31 | 0 |
| | Bangladesh | 7684 | 87.82 | 0.05 | Burkina Faso | 703 | 51.43 | 0.32 |
| | Belgium | 1602 | 1.13 | 0.07 | Djibouti | 318 | 15.79 | 0 |
| | Benin | 2361 | 25.21 | 0.25 | Egypt | 596 | 79.16 | 0.03 |
| | CÃ´te d’Ivoire | 3443 | 51.64 | 0.12 | Kuwait | 5 | 62.27 | 0 |
| | Gambia | 3614 | 38.58 | 0.2 | Oman | 300 | 85.84 | 0.01 |
| | Guinea | 18728 | 51.04 | 0.26 | Qatar | 21 | 31.96 | 0.01 |
| | Guinea-Bissau | 17176 | 75.79 | 0.17 | Rep. of Korea | 1364 | 58.93 | 0.03 |
| | Indonesia | 7628 | 85.21 | 0.09 | Saudi Arabia | 73 | 82.23 | 0.11 |
| | Italy | 3153 | 49.73 | 0.11 | Singapore | 105 | 4 | 0 |
| | Liberia | 49338 | 8.43 | 0.11 | South Africa | 901 | 58.77 | 0.22 |
| | Malaysia | 18647 | 45.65 | 0.03 | United Arab Emirates | 16 | 82.84 | 0 |
| | Mauritius | 2176 | 55.84 | 0.06 | | | | |
| | Mozambique | 7578 | 73.05 | 0.2 | | | | |
| | Netherlands | 5346 | 0.48 | 0.06 | | | | |
| | Nigeria | 1499 | 44.17 | 0.18 | | | | |
| | Philippines | 4554 | 73.28 | 0.05 | | | | |
| | Portugal | 7523 | 78.43 | 0.09 | | | | |
| | Romania | 10787 | 22.01 | 0.44 | | | | |
| | Russian Federation | 31096 | 28.97 | 0.85 | | | | |
| | Spain | 2390 | 65.22 | 0.27 | | | | |
| | Sri Lanka | 2499 | 87.36 | 0.06 | | | | |
| | Togo | 1909 | 34.08 | 0.35 | | | | |
| | United Kingdom | 2203 | 14.05 | 0.09 | | | | |

Source: FAO STAT

## Economics of methane emission associated with rice exports from India

As observed in previous paragraphs share of Indian rice exports in total Indian rice production ranged between 2.42 to 11.31 per cent across years. Accordingly, methane emission associated with rice trade ranged between 2.42 to 11.31 per cent of total methane emission from rice production in India.

According to FAOSTAT methane emission per ton of rice in India ranged between 33.6 to 39.5 Kg per ton of rice production during 2009 to 2017. Sapkota *et al.,* (2019) reported emission of methane from paddy cultivation in range between 1425 to 6335 kg $CO_2$ per ha (across different states of India) with a mean value of 3188 Kg $CO_2$ per hectare in the year 2012. Thus, with average production of rice of 2.43 tons per ha (in 2012), carbon emission works out to be 1311.93 Kg per ton of rice *i.e.,* 62.5 Kg methane per ton of rice production (with GWP *i.e.* Global Warming Potential of methane = 21). According to India's second biennial update report to the United Nations Framework Convention on Climate Change, methane emission worked out to be 33 kg per ton of rice production in 2014 (BUR, 2019). According to GHG platform India computation, methane emission per ton of rice ranged from 30.9 to 38.4 kg between 2005 and 2015, with declining emission intensity over years. These wide variations were due to different time periods considered as well as due to differences in computational methods. FAOSTAT data is based on single emission factor (10.556 g methane per square meter area); on the other hand, GHG platform estimates are based on ecology specific emission factors. Sapkota *et al.,* (2019) estimated methane emission using farm level data with "Cool farm tool".

Using IPCC method (following GHG platform India) thereby using different emission factors for different rice ecosystems, methane emission and in turn carbon dioxide ($CO_2$) emission associated with Indian rice exports were computed in the current study. These methane emissions were converted into carbon equivalent by using a GWP factor of 21(IPCC,1995) for comparing with other study results. Using IMF bench mark of 75 US$ carbon price per ton of $CO_2$ (Parry *et al.,* 2021), carbon costs associated with rice exports (US$ per ton of rice) from India are computed. These costs worked out to be 4.68 to 5.2 per cent of unit value of export in the case of basmati rice (**Table 9**). Carbon costs share in unit value of exports ranged between 9.65 to 13.48 in the case of non-basmati rice and 4.84 to 8.79 per cent in the case of (Basmati + Non-basmati) rice exports in different years, indicating the possible increase in price of exports if carbon pricing is implemented in practice. If GWP factor of 28 (IPCC,2014) is used, the carbon taxes/costs will further increase. Hence carbon taxes if implemented may affect production, trade competitiveness, trade extent, trade pattern (Dumortier and Elobeid, 2021, Chayun 2020). Codjo *et al.,* (2021) in the context of Benin, reported that consumers in general were price sensitive and substitution between imported and domestic rice was limited. Implementation of carbon price unilaterally may lead to squeeze in margin of producers and carbon leakage. Already squeeze in margin of Indian farmers from rice exports due to some policies in rice importing countries was reported by Kumar (2019).

Among 47 trade partners identified as top 5 destinations of Indian rice exports, only with respect to 34 countries data pertaining to paddy harvested area and emission intensity is available in FAOSTAT database. Out of these 34 countries in 27 countries emission intensity was higher than that of emission intensity of India in 2017 (**Table 10**). But in these 27 countries paddy harvested area was lower than that of India. In the rest 7 countries, both emission intensity as well as paddy harvested area was lower than that of India. This indicates carbon leakage to some extent through rice exports from India.

India's projected rice supply in 2029 ranges from 138-145 million tons (NITI Ayog, 2018). OECD-FAO (2020) projects that India will export 14 per cent of its total rice production in 2029. Accordingly, share of trade led methane emission in total emission from rice production is expected to increase. However, over the years EI (Emission intensity in kg $CO_2$ equivalent per Kg product) in rice production in India is declining. EI of India in rice production was 1.5878 in 1961 declined

**Table 9. Carbon cost of rice exports**

| Year | Methane Kg/ton rice | $CO_2$ equivalent per ton (in tons) | Carbon cost (US$ per ton rice) | Unit value US $/ton | | | Share of carbon cost in unit value (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Basmati | Non-basmati | Total rice | Basmati | Non-basmati | Total rice |
| 2009-10 | 35.08 | 0.74 | 55.25 | 1180.78 | 572.50 | 1141.41 | 4.68 | 9.65 | 4.84 |
| 2010-11 | 34.09 | 0.72 | 53.69 | 1054.72 | 497.21 | 1031.63 | 5.09 | 10.80 | 5.20 |
| 2011-12 | 32.17 | 0.68 | 50.67 | 973.84 | 433.37 | 672.57 | 5.20 | 11.69 | 7.53 |
| 2012-13 | 31.15 | 0.65 | 49.07 | 1001.46 | 385.68 | 595.62 | 4.90 | 12.72 | 8.24 |
| 2013-14 | 31.11 | 0.65 | 48.99 | 1304.49 | 416.19 | 722.06 | 3.76 | 11.77 | 6.79 |
| 2014-15 | 31.17 | 0.65 | 49.09 | 1190.99 | 394.99 | 642.06 | 4.12 | 12.43 | 7.65 |
| 2015-16 | 30.84 | 0.65 | 48.58 | 855.08 | 360.37 | 552.42 | 5.68 | 13.48 | 8.79 |
| 2016-17 | 29.88 | 0.63 | 47.06 | 816.47 | 379.82 | 541.34 | 5.76 | 12.39 | 8.69 |
| 2017-18 | 28.78 | 0.60 | 45.33 | 992.33 | 397.82 | 587.72 | 4.57 | 11.40 | 7.71 |
| 2018-19 | 27.92 | 0.59 | 43.97 | 1070.58 | 399.75 | 647.61 | 4.11 | 11.00 | 6.79 |
| 2019-20 | 27.53 | 0.58 | 43.37 | 989.03 | 404.70 | 678.97 | 4.38 | 10.72 | 6.39 |

to 0.7067 in 2017 (FAOSTAT). Hence it is the larger area under paddy, which is contributing to higher methane emission from rice cultivation in India. The adoption of the System of Rice Intensification (SRI) resulted in emission reduction to the extent of 0.18 million tons of $CO_2$ equivalent during 2010-16 and Direct Seeded Rice (DSR) led to emission reduction of 0.17 million tons of $Co_2$ equivalent from 2014-16 (BUR,2015).

As of now in several countries carbon tax is limited to energy sector only but still having differential effect on competitiveness of different commodities (Chayun, 2020). Frank *et al.,* (2021) reported that there can be increase in global rice price to the extent of around 65% at global carbon tax of 150$ per ton of $CO_2$ equivalent on direct GHG emission across world regions and without consideration of adjustments in production system.

## Options available to address environmental externalities

### *Nation level measures*

Davis *et al.,* (2019) viewed that increasing the area under coarse cereals improves nutritional supply, increases climate resilience (fewer calories lost during an extreme dry year) reduces GHG emissions and demand for irrigation water and energy in India. However, as there is wide spatial variation in water footprint of rice within Indian states, change in crop planning such that total blue water footprint can be reduced can be a measure (Santosh *et al.,* 2021). Further import export policy of India should permit water intensive crops exports from the states where the blue WF are lower and the net gains from the international trade leads to positive virtual water balance and restrict exports from hotspot areas facing sustainability issues in water (Santosh *et al.,* 2021). Kumar (2019) observed that only in three states *viz* Punjab, Haryana and Tamil Nadu, export price of non-basmati rice was higher than economic costs consistently during 2013-14 to 2016-17. However, Chand *et al.,* (2021) observed that blue water footprint constituted over 70% of the total water footprint of rice in the irrigated north western zones of Punjab and Haryana. Hence they suggest incentivizing adoption of alternative technologies like Direct Seeded Rice (DSR), Alternate Wetting and Drying (AWD) and short duration water stress resistant rice varieties in these regions. Vetter *et al.,* (2017) reported that changing the water regime from continuously flooded to multiple drainage periods reduces methane emission by 9-fold. Gartaula *et al.,* (2020) reported potential of DSR and Machine transplanted rice in GHG mitigation in India. Promoting adoption of low carbon technologies (like SRI, AWD) through carbon premium/credit (incentive payment for reduced carbon emission) can be one policy option that need to be explored for not only reducing carbon emission but also water saving.

For this water saving and reduced carbon emission through adoption of SRI or AWD or DSR in different rice ecosystems/zones/states need to be evaluated.

**Table.10 Paddy area and emission intensity in paddy production in selected years in top five destinations of rice export from India**

| Country | Emission intensity (Kg $CO_2$ equivalent/kg product) | | Paddy area (ha) | | Paddy productivity (Kg/ha) | |
|---|---|---|---|---|---|---|
| | 2010 | 2017 | 2010 | 2017 | 2010 | 2017 |
| Australia | 0.72 | 0.74 | 18931 | 82204 | 10390 | 9821 |
| Bangladesh | 0.69 | 0.7 | 11529000 | 11615000 | 4342 | 4662 |
| Benin | 0.44 | 0.26 | 47058 | 78969 | 2656 | 3529 |
| Bhutan | 0.87 | 0.67 | 22815 | 21202 | 3140 | 4074 |
| Burkina Faso | 2.88 | 2.98 | 133737 | 165086 | 2024 | 1972 |
| CÃ´te d’Ivoire | 0.33 | 0.38 | 394868 | 813790 | 3055 | 2605 |
| Egypt | 0.92 | 0.85 | 459525 | 549688 | 9422 | 9025 |
| Ethiopia | 1.33 | 1.29 | 29866 | 53107 | 3027 | 2844 |
| Gambia | 4.77 | 7.07 | 86150 | 65854 | 1159 | 456 |
| Guinea | 2.31 | 2 | 1465953 | 1805878 | 1101 | 1217 |
| Guinea-Bissau | 0.83 | 0.96 | 100510 | 104923 | 2082 | 1573 |
| **India** | **0.8** | **0.71** | **42862400** | **43774070** | 3359 | 3849 |
| Indonesia | 1.12 | 1.08 | 11797000 | 11471000 | 5025 | 5181 |
| Iran | 1.29 | 1.17 | 563517 | 396877 | 4419 | 4929 |
| Iraq | 1.9 | 1.28 | 47974 | 54283 | 3248 | 4898 |
| Italy | 2.08 | 1.95 | 247700 | 234133 | 6122 | 6825 |
| Liberia | 0.39 | 0.36 | 251230 | 233590 | 1179 | 1060 |
| Madagascar | 1.12 | 0.98 | 1307043 | 730000 | 3625 | 4932 |
| Malaysia | 1.37 | 1.07 | 677884 | 685548 | 3636 | 3750 |
| Mozambique | 1.5 | 2.19 | 226593 | 325000 | 1137 | 425 |
| Nepal | 0.92 | 0.75 | 1481289 | 1552469 | 2716 | 3369 |
| Nigeria | 1.42 | 1.3 | 2432630 | 5627700 | 1839 | 1391 |
| Pakistan | 1.23 | 0.97 | 2365300 | 2900595 | 3059 | 3853 |
| Philippines | 2.13 | 1.95 | 4354161 | 4811808 | 3622 | 4006 |
| Portugal | 2.38 | 2.25 | 29120 | 28944 | 5845 | 6211 |
| Rep. of Korea | 0.84 | 0.81 | 892074 | 754713 | 6514 | 7003 |
| Romania | 5.43 | 8.08 | 12403 | 9125 | 4966 | 4746 |
| Russian Federation | 2.13 | 2.47 | 200878 | 185649 | 5280 | 5314 |
| Senegal | 0.49 | 0.48 | 147208 | 305934 | 4103 | 3306 |
| South Africa | 55.64 | 56.49 | 1184 | 1113 | 2588 | 2763 |
| Spain | 2.31 | 2.51 | 122184 | 107604 | 7594 | 7762 |
| Sri Lanka | 0.79 | 1.48 | 1060360 | 791679 | 4056 | 3010 |
| Timor-Leste | 1.35 | 1.39 | 36548 | 20681 | 3090 | 3107 |
| Togo | 0.24 | 0.29 | 47403 | 84395 | 2323 | 1665 |
| Viet Nam | 0.91 | 0.91 | 7489400 | 7708534 | 5342 | 5548 |

Other challenge in implementing carbon pricing in agriculture is measuring carbon emission/storage capacity at farm level on yearly basis. However, some studies (Folkhard *et al.,* 2021) are exploring ways to integrate agriculture into carbon pricing, by focusing on aggregate collection points of products. Potential of carbon credits in sustainable rice cultivation was also reported in the context of USA (Proville *et al.,* 2021), Sri Lanka (Razmy *et al.,* 2013), and practice of carbon credits in sustainable rice cultivation was reported by EDF (2019) in the context of USA.

Reducing subsidies in water stressed regions and strengthening rice procurement in eastern system is also being viewed as some measures to better planning of rice cultivation in India (Chand *et al.,* 2021). Batini (2019) suggests that Governments should make the adoption of on-farm conservation practices a condition for receiving farm subsidies. Breeding low-emitting rice varieties could be one effective mitigation strategy (Chirinda *et al.,* 2018; Balakrishnan *et al.,* 2018).

### *International measures*

Hoekstra (2011) argued that addressing water problems at the river basin level is not always sufficient. They identified four major issues to be addressed at global scale *viz*., efficiency, equity, sustainability and security of water supply in a globalized world. The possible arrangements that address these issues are (i) an international protocol on water pricing (ii) a pollution tax and international nutrient housekeeping (iii) water labelling of water intensive products (consumer perspective) or (Producer oriented) water certification of industries or retailers (iv) minimum water rights (v)maximum allowable levels of water use to be defined at basin level and aggregated at national level according to the philosophy of fair shares (vi) Implementing the water neutral concept(water offset by investing in water conservation measure or in water supply to the poor) (vii) International business code for multinationals in the water sector and tradable water footprint permits. According to the global water governance approach, local measures that include opportunity costs and environmental costs in agricultural water prices will not be successful. Several policy instruments have therefore been suggested like international water pricing protocol, virtual water border taxes, tradable water footprint permits. In the absence of global natural resource market, Chen *et al.,* (2021) opine that resource tax may be an effective means to reduce global environmental inequality and resource mismatch. Rosa *et al.,* (2019) view that in an increasingly water scarce world, Governments could take specific actions targeting unsustainable irrigation practices by penalizing the associated imports. By identifying trade links that are responsible for unsustainable virtual water trade, policies are needed to achieve sustainable water and food security goals in the coming decades. Cheptea and Dupraz (2021) observed that countries' irrigation behaviour is strongly linked to the global prices of crops, and the export price effect is stronger when countries are net exporters of irrigated crops. Accordingly, they suggest that trade policies like product specific export taxes or binding export quotas linked to the embedded irrigation water can be used as tools in water management.

Batini (2019) suggested that at International level, a fund could be setup to compensate countries for foregoing trade in commodities whose production threatens critical ecosystem. As under the UNFCCC (United Nations Framework Convention on Climate Change) countries are responsible only for emissions within their own borders, Parry (2019), Parry *et al.,* (2021) suggested carbon tax for reducing GHG emission. Further to reduce emissions to a level consistent with a 2 degrees C target, a global average carbon price of 75$ a ton was advocated (Parry, 2019; Parry *et al.,* 2021).

A contentious debate is going on regarding appropriate basis for GHG emission measurement *i.e.,* production based measurement vs consumption based measurement. Amidst this debate Bontems and Calmette (2019) proposed a new way of assessing environmental responsibility at the country level taking into account their trade balance in terms of carbon. For this, they examined the extent to which trade flows for a given country increases or decreases global emissions relative to the virtual situation where imports would have been produced in the consumer country. They argued that it would be fair for countries to retain responsibility for the additional emissions they create when trading. Compared to the consumer based rule, the modified rule will increase (reduce) a country's responsibility when it is creating more (less) emissions by exporting towards cleaner countries than by importing from less clean countries. Compared to pure producer based rule this will create incentives to reduce emission if and only if the country under scrutiny is a global net importer from less emission efficient countries. However, the modified rule diminishes the incentive to reduce emission when the country is a global net exporter towards less emission efficient countries. Compared to a pure consumer based rule, the modified rule always increases the incentive to reduce emission. Jakob *et al.,* (2021) proposed responsibility sharing for trade related emissions based on economic benefits from emitting free of charge (*i.e.,* when carbon emissions do not carry price). Under this proposal, a certain share of emission associated to import as well as exports will be assigned to each country. However, these studies (Bontems and Calmette, 2019; Jakob *et al.,* 2021) are focussing on aggregate emission or emission intensity per unit of GDP of countries in bilateral trade relationships but not related to any specific commodity.

Currently Emission Trading Systems (ETS) wherever operational are focusing only on non-agricultural sectors. According to Jennifer and Adam (2019), key objections to the inclusion of agricultural emissions in the ETS are the lack of effective mitigation technologies and the limited ability of farmers to pass the costs of compliance on to their predominately international customers. In this backdrop, Chirinda *et al.,* (2018) opined that increasing consumer awareness and influencing consumer preference towards more sustainably produced rice will contribute towards incentivizing the adoption of good management and technological choices.

## Conclusions

It is evident that there are several technological and policy options available for reducing water use and GHG emission from rice production and trade. In some cases, these options become complementary. For instance, carbon premium/ credit policy can be used to accelerate adoption of technologies like SRI, DSR, AWD at country level. This will aid in not only reducing water consumption but also reduce GHG emission. But for implementing this option carbon saving due to adoption of these technologies need to be evaluated at different states/zone/ecosystem levels. Some trade policy instruments like carbon tax can also be used to influence rice trade extent and pattern. But while applying trade instruments, compliance with WTO rules must be ensured. Parry *et al.,* (2021) proposed International Carbon price floor among large emitter countries initially to fossil fuel sector but later extending to all sectors. Thus out of several options available, more economically feasible and accep table options need to be identified by in depth studies. Further, for addressing environmental externalities associated with rice trade, efforts at multi-country level are needed for effectiveness in line with "Climate Club " concept.

**Limitations of the study**: Heterogeneity across states in paddy Water footprint and methane emissions are not considered in the current study. Further in the study, focus is limited to methane emission only, other GHG gases are not considered. Further in calculation of water footprint and methane (Carbon) emission, contribution of transport was not accounted for.

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