Paddy Water Environ (2005) 3: 39–46
DOI 10.1007/s10333-005-0071-x

ARTICLE

Meinhard Breiling · Shizuka Hashimoto · Yohei Sato · Gilbert Ahamer

# Rice-related greenhouse gases in Japan, variations in scale and time and significance for the Kyoto Protocol

Received: 3 June 2004 / Accepted: 14 December 2004 / Published online: 10 February 2005


**Abstract** The contribution of rice production to the three major greenhouse gases $CO_2$, $CH_4$ and $N_2O$ in 1990, the base year of the Kyoto protocol is investigated for Japan. For the $CO_2$ assessment, we use a top-down life cycle approach, $CH_4$ is assessed using the Japanese GHG emission inventory and $N_2O$ is assessed according to the ratio of rice area divided by the total area of agricultural soils. In total, 1.6% of greenhouse gas (GHG) emissions in 1990 originated from rice production. Next, we assess regional variations in nine rice-producing regions, based on the $CO_2$ data of 1990. General trends in rice production from 1960 to 2000 and data from the Japanese GHG emission inventory since 1990 are used to assess variations in time. The rice-related GHG emissions decreased to 1.05% of the total GHG emissions in 2001 and will be less than half the 1990 level in 2012, mainly due to the decrease in rice production. Contrary to the trend in GHG emissions of rice, overall GHG emissions increased as rice production fulfils important roles, in mitigating global warming and in adapting to changing climates. The protection of rice production is required to counter the increase of GHG emissions in transportation, waste and domestic sectors and to minimize problems related to landscape, water and natural hazard management.

**Keywords** Rice production · Rural and regional planning · Global warming · Top down life cycle assessment

M. Breiling (✉)
Department for Urban Design and Landscape Architecture,
Technical University Vienna,
Operngasse 11,
A-1040 Wien, Austria
e-mail: meinhard.breiling@tuwien.ac.at

S. Hashimoto
Graduate School of Agriculture and Life Sciences, The University of Tokyo,
Yoyoi 1-1-1,
Bunkyo-ku Tokyo, 113-8657, Japan

Y. Sato
Department of Bio-Business Management and Information,
Faculty of International Agriculture and Food Studies, Tokyo University of Agriculture,
1-1-1, Sakuragaoka,
Setagaya-ku Tokyo, 156-8502, Japan

G. Ahamer
University of Graz, Environmental Systems Analysis,
Obere Teichstr. 25,
8010 Graz, Austria

## Introduction

Rice is the most important agricultural commodity of Japan and rice covered 7% of its territory in 1990. More than 99% of the rice-cultivated area is paddy and less than 1% is upland rice. Some 3 million Japanese farms produced more than 10 billion kg of rice. Divided by the total population of 123 million people, this gives an average of 75 kg production per person, while the annual consumption was 68 kg per person (MAFF 2003). The price of rice in Japan was 8 times higher than the world market price, and the consumer paid the same amount of money as the producer was paid by the state. Thus rice production is highly subsidised and does not follow the world market. During the 1990s, Japanese rice production was questioned because of anthropogenic global warming and the emissions of greenhouse gases from rice production. However, rice production is important to sustain the rural population of Japan and therefore has to be regarded in a social context.

The Kyoto Protocol, which was accepted by Japan in June 2002, targets the reduction of six greenhouse gases (GHGs): carbon dioxide (CO2); methane (CH4); nitrous oxide (N2O); hydro fluorocarbons (HFCs); per fluorocarbons (PFCs); and sulphur hexafluoride (SF6). The target given to Japan for the first commitment period (2008 to 2012) was to reduce average emissions of greenhouse gases by six percent from the base year (1990 for carbon dioxide, methane and nitrous oxide, and 1995 for hydro fluorocarbons, per fluorocarbons, and sulphur hexafluoride). At the same time, the accuracy of the emission estimates was to be improved. Official Japanese GHGs emissions

**Table 1** Japanese greenhouse gases in Gigagrams of $CO_2$ equivalent

| Year/Gas | $CO_2$ | $CH_4$ | $N_2O$ | $HFC_s$ | $PFC_s$ | $SF_6$ | Total |
|---|---|---|---|---|---|---|---|
| 1990 | 1122.1 | 24.8 | 40.2 | – | – | – | 1187.1 |
| 1995 | 1210.9 | 23.4 | 40.8 | 20.0 | 11.5 | 16.7 | 1323.4 |
| 1999 | 1228.2 | 21.3 | 35.1 | 19.5 | 11.1 | 8.4 | 1323.6 |
| 2000 | 1238.7 | 20.9 | 37.8 | 18.3 | 11.5 | 5.7 | 1322.9 |
| 2001 | 1213.7 | 20.3 | 35.4 | 15.6 | 9.9 | 4.5 | 1299.4 |

Source: Ministry of Environment 2003, National GHGs Inventory Report of JAPAN

(Ministry of Environment 2003) are described according to the best practice method of the International Panel on Climate Change (IPCC) in Table 1.

Agriculture and in particular rice production has been named as a significant contributor to GHGs. Our aim is to estimate the magnitude not only of direct rice-related emissions in the GHG database, but also of GHGs hidden in other categories, primarily energy, industry and waste.

We divide rice related GHGs into primary and secondary emissions. Primary GHGs relate directly to rice and agriculture and depend on the metabolism of the rice plant and the soil where it grows. Climate and water dynamics play a most important role in these kinds of emissions. Secondary emissions relate to the inputs of Japanese rice production including agricultural machinery, fertilizer, pesticides and others. Secondary GHGs are included in other non-agricultural source categories such as fuel combustion emissions and industrial processes. Particular methods are necessary to translate from existing categories in the GHG inventory database to make secondary greenhouse gases of rice production visible and we describe the method of calculation later on. The main sectors of the Japanese GHG inventory are described in Table 2.

In the first two sections of this paper, we reconstruct the picture of rice related GHG emissions in 1990, the base year of the Kyoto protocol, and provide figures for the primary and secondary GHGs of Japan, expressed as a percentage of the total GHG emissions in $CO_2$ equivalent. We discuss some uncertainties related to these figures in accordance with the good practice guidance in national greenhouse gas inventories (IPCC 2000).

Then we assess the spatial and time variations in GHG emissions in Japan. Thus we can discuss the variations within Japan and provide some assumptions about regional variations in 1990 as compared to the whole of Japan. But is 1990 still a representative year for rice production? Here, we combine the estimates of 1990 with major trends in rice production in the second half of the last century and extrapolate this trend to the period 2008 to 2012.

In a final discussion, we relate rice production and the services related to rice production to the overall picture in Japan. What is the likely development in Japanese rural areas and what else is relevant other than resource management? What can be the future role of rice production in Japan?

## Assessment of primary emissions related to rice production: $CH_4$ and $N_2O$

Of the primary emissions of rice production, the most important gas is $CH_4$. In developing countries, $CH_4$ emissions were considered to be the major GHG. Rice production was assumed to contribute in the range of 6 to 27% of global $CH_4$ emissions (Neue 1993). Later on, after some major efforts to assess $CH_4$ emissions from rice production (Wassmann et al. 2000) the range was reduced to 2 to 5% of global $CH_4$ emissions. According to a review (Sass et al. 1999), the estimates of the contribution of rice production became ever smaller with the increase of measurement sites. In particular, the knowledge of how fluxes change in space and time is inaccurate. Usually measurements covered only the vegetation period and variations are large. According to a recent personal communication with Neue (2003), rice is no longer considered to be a major contributor of global $CH_4$.

In the *1995 IPCC Guidelines*, the estimation of $CH_4$ emissions from paddy fields is described as a function of the $CH_4$ emission factor, area of rice cultivated and the season length. One critical default parameter is the $CH_4$ emission factor, which is based upon temperature. The seasonally integrated $CH_4$ flux depends much more on the input of organic carbon, water, time and duration of drainage and soil type than on local temperature.

The following equations specify how to assess $CH_4$ emissions (1) based on specific variables for local emission factors (2) and originate from the revised 1996 IPCC Guidelines (1997, Eqs. (4.41) and (4.42), chapter 4, p. 77 and p. 80) in accordance with the IPCC best practice guidance (IPCC 2000, p.399–417):

$$F = \Sigma_i \Sigma_j \Sigma_k (EF_{ijk} \times A_{ijk} \times 10^{-12}) \quad (1)$$

$F$ = estimated annual regional or national emissions of methane from rice production in Tg per year, $EF_{ijk}$ = a seasonally integrated emission factor for $i$, $j$, and $k$

**Table 2** Japanese greenhouse gases in Gigagrams of $CO_2$ equivalent according to sectors

| Year/sector | Energy | Industrial processes | Solvent and other product use | Agriculture | Waste | Total |
|---|---|---|---|---|---|---|
| 1990 | 1058.1 | 64.8 | 0.3 | 39.0 | 24.9 | 1187.1 |
| 1995 | 1140.2 | 115.2 | 0.4 | 37.1 | 30.4 | 1323.4 |
| 1999 | 1163.2 | 92,6 | 0.4 | 34,4 | 33.0 | 1323.6 |
| 2000 | 1171.8 | 92.8 | 0.3 | 34.1 | 33.9 | 1322.9 |
| 2001 | 1149.5 | 82.1 | 0.3 | 33.8 | 33.6 | 1299.4 |

Source: Ministry of Environment 2003, National GHGs Inventory Report of JAPAN conditions in g $CH_4$ $m^{-2}$, $A_{i,j,k}$ = annual harvested area for $i$, $j$, and $k$ conditions, in $m^2$. $i$, $j$, and $k$ = represent different ecosystems, water management regimes and other conditions under which $CH_4$ emissions from rice may vary (e.g. addition of organic amendments)

$$EF_i = EF_c \times SF_w \times SF_o \times SF_s \quad (2)$$

$EF_i$ = Adjusted seasonally integrated emission factor for a particular harvested area, $EF_c$ = Seasonally integrated emission factor for continuously flooded fields without organic amendments, $SF_w$ = Scaling factor to account for the differences in ecosystem and water regime, $SF_o$ = Scaling factor to account for amount and kind of organic amendments, $SF_s$ = Scaling factor for soil type, if available.

The revised methodology is a function of the emission factor integrated over a cropping season for a particular rice water regime, a given organic amendment, and of the annual harvested area cultivated under these conditions. The revisions to the method use internationally agreed definitions for rice eco-systems, classified according to the water regime and a range of $CH_4$ emission scaling factors relative to continuously flooded rice eco-systems and for soils without organic amendment. A default seasonally integrated emission factor is provided for the continuously flooded regime, without organic amendment. Yearly estimates are based on a three-year average value (IPCC 1997).

Japanese studies have focused on the natural cycle during rice production and $CH_4$ (Yagi and Tsuruta 1994; Yagi and Minami 1998). The official figure for $CH_4$ emissions in 1990 was 24,795,460 tons of $CO_2$ equivalents (Ministry of Environment 2003). The $CH_4$ from rice was 7,075,730 tons of $CO_2$ equivalents. This figure relates to the cultivation of 1,984.127 hectares and an average of 3.57 tons of $CO_2$ equivalent from one hectare of Japanese rice field. This corresponds to an average of 17 g $m^{-2}$ of $CH_4$ emissions using the factor of 21 to calculate the global warming potential in $CO_2$. Rice contributed 29% of all the $CH_4$ emissions of Japan. However variations within Japan were large. The value for Tsukuba was smaller than 1.1 g $m^{-2}$ $CH_4$, while the highest value was in Kawachi with 45 g $m^{-2}$ $CH_4$ (IPCC/UNEP/OECD/IEA 1997; citing Yagi and Minami 1990; Minami 1994). If we take the above proposed average value (17 g $m^{-2}$), the $CH_4$ emissions contributed to 0.6% of total Japanese greenhouse gas emissions in 1990.

In addition to $CH_4$, the role of $N_2O$ has become increasingly important. In the GHG inventory, the rice-related $N_2O$ emissions are not explicitly assessed in connection with rice growing, but are related to agricultural soils. $N_2O$ might even be considered to be a larger problem than $CH_4$ in the future. $N_2O$ emissions from agricultural soils and manure management were revised after 1995 (IPCC/UNEP/OECD/IEA 1997 and IPCC 2000, Eq. (4.21), p. 4.54)

$$N_2O_{Direct} - N = \sum_i \{(F_{SN} + F_{AM})_i \cdot EF_i + (F_{BN} + F_{CR}) \cdot EF_1 + (F_{os} \cdot EF_2)\} \quad (3)$$

$N_2O_{Direct}$ = Emissions of $N_2O$ in units of Nitrogen, $F_{SN}$ = Annual amount of synthetic fertilizer nitrogen applied to soils adjusted to account for the amount that volatilizes as $NH_3$ and $NO_x$, $F_{AM}$ = Annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilizes as $NH_3$ or $NO_x$, $F_{BN}$ = Amount of nitrogen fixed by N-fixing crops, cultivated annually, $F_{CR}$ = Amount of nitrogen in crop residues returned to soil annually, $F_{OS}$ = Area of organic soils cultivated annually, $EF_1$ = Emissions factor for emissions from N inputs (kg $N_2O$-N/kg N input), $EF_2$ = Emissions factor for emissions from N organic soil cultivation (kg $N_2O$-N/ha-yr), $EF_i$ = Emissions factor developed for $N_2O$ emissions from synthetic fertilizer and animal manure application under different conditions $i$.

The reference equation includes more sources of $N_2O$ from agricultural activities and recommends $N_2O$ emission factors, either as a dynamic factor ($EF_i$), that depends on local conditions and the relation of soil type and climate to other biological, chemical and physical parameters, or as a stable factor ($EF_1$ and $EF_2$). The revised method accounts for the application of N-fertilizers to the soil and N uptake in crops and tracks the flow of N as it moves through the food chain. Three categories of $N_2O$ sources are identified: direct emissions from agricultural soils, emissions from animal production, and other $N_2O$ emissions caused by agricultural activities. The revised method includes previously omitted $N_2O$ sources. Using this method, global $N_2O$ emission estimates imply that atmospheric $N_2O$ input from agricultural production as a whole has apparently been previously underestimated by at least 70%.

For assessing the rice-related $N_2O$ emissions we only consider soil, but manure generation by farm animals could be considered to be rice-related as well. According to the principles of the best practice advice, we apply a simple model. 45.5% of all cultivated land was under rice in 1990. We use this ratio to assess the rice-related $N_2O$ emissions. Some 11% of the total Japanese $N_2O$ emissions or 4,434,180 tons of $CO_2$ equivalents originated from rice and contributed 0.37% of the total amount of the Japanese GHG emissions.

Uncertainties in estimating $CH_4$ and $N_2O$ together are high and there are no measurements of total greenhouse gas emissions for the whole year. $N_2O$ and $CH_4$ are likely to be in a trade off, but this relation is not yet well understood (Tsuruta 2002). In contrast to other Asian countries, there is only one harvest of rice per year in Japan, even though the south of Japan would climatically qualify for two harvests. In some cases, vegetables are grown in sequence with rice on the same soils. To some perhaps minor extent, even $CO_2$ can play a role in agricultural soils. Efforts are being made to find out how far the other greenhouse gases $HFC_s$, $PFC_s$, $SF_6$ are involved in the natural cycle of rice production. However, at this stage, we only consider $CH_4$ and $N_2O$. Considering the existing uncertainties in emission estimates, about 1% of the 1990 Japanese GHG emissions, and some 30% of GHGs related to agriculture, accounting for 11.5 Tg $CO_2$ equivalents, are caused by rice-related primary emissions of $CH_4$ and $N_2O$.

### Assessment of secondary emissions related to rice production: $CO_2$

In highly industrialised countries such as Japan, we can consider rice to be an industrial product. Thus we can calculate the share of rice-related greenhouse gas emissions using life-cycle analysis (LCA) as a method (Breiling et al. 1999). The inputs relate to different activities of rice production, preparation of rice field and canalisation system, seedling phase, growing phase, harvesting phase and post-harvesting phase. Inputs include agricultural machinery, fuels and other energy, pesticides, fertilizer and many more that are registered in the life-cycle inventory. Connected to every input we find other resource inputs and emissions. More sophisticated software for life-cycle analysis includes several thousand constituents. The amounts of constituents in inputs are summed up to a total output of the product.

Problems in accounting may arise in cases of co-generation of several products. This applies also to rice production. We have the production of rice straw or "tatami" mats, and the provision of important services such as the maintenance of rural landscapes that provide flood protection and recreational areas for urban people. The splitting between multiple products is an often discussed and not entirely resolved issue in life-cycle assessment. In our case, we had a further problem in that the base year of the Kyoto protocol 1990 had passed and a so-called bottom-up life-cycle analysis was not possible. Further, it would have been difficult to make a bottom-up inventory for rice production, as there are many production methods and each farmer has preferences as to how to manage the land and how many inputs to give. To obtain representative Japanese data, we would have to interview thousands of farmers in different climatic regions, using different variants of rice.

Our prime interest is not growing resource use and optimization of resource use, but the assessment of greenhouse gases. We had to find a different method; a top-down life-cycle assessment based on economic input and output tables (Yoshioka et al. 1998). There are over 4,000 products considered in the economic input-output matrix and one can track emissions in a similar way to tracking the flow of money, originally described by a so-called Leontieff matrix. However, only major constituents, such as $CO_2$, can be covered by this approach, as less frequent constituents may show significant errors. Originally developed for economic analysis for finding the multiplication effect of expenditures, a transformation of the original input-output matrix from economy to resource use is necessary to assess the amount of GHG emissions instead of the flow of money.

All necessary inputs for activity $x_{j(=\text{rice})}$ are expressed in Eq. (4).

$$a_j = \begin{pmatrix} a_{1j} \\ \vdots \\ a_{ij} \\ \vdots \\ a_{nj} \end{pmatrix} \cdot x_j \tag{4}$$

Then all necessary inputs for all process activities are expressed in Eq. (5).

$$\sum_{j=1}^{n} a_j x_j = \begin{pmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & \vdots & a_{2j} & \vdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_j \\ \vdots \\ x_n \end{pmatrix} = Ax \tag{5}$$

By-products and emissions are expressed as follows.

$$y = Ex = \sum_{j=1}^{n} e_j x_j = \begin{pmatrix} e_{11} & \cdots & e_{1j} & \cdots & e_{1n} \\ e_{21} & \vdots & e_{2j} & \vdots & e_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ e_{n1} & \cdots & e_{nj} & \cdots & e_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_j \\ \vdots \\ x_n \end{pmatrix} \tag{6}$$

The following condition assumes $\boldsymbol{f}$ as a vector of final demand (Yoshioka et al. 1998). This mathematical formation is different from input-output analysis in economics. Life-cycle inventories must allocate resource requirements and emissions to multiple products from a single process, which is impossible in input-output analyses based on the principle of one activity-one commodity. A modification of the principle is required to adjust for life-cycle assessments including recycling or multiple productions.

For this purpose, the vector $\boldsymbol{x}$ is defined not to be materials, but to be processes. Then it follows that $Ax$ and $Ex$ represent the materials to be inputted into or outputted from the process $x$. Thus it is possible to include multiple outputs or emissions such as $CO_2$, $NO_x$, $SO_x$ and heavy metals in Eq. (6). Based on Eqs. (5) and (6), we obtain the following relation in Eq. (7).

$$\begin{aligned} Ex &\geqslant Ax + f \\ (E - A)x &\geqslant f \end{aligned} \tag{7}$$

In order to determine $\boldsymbol{x}$, a criterion function for optimisation or simulation such as the rojit function is needed, on which actual systems depend. If actual systems are determined to minimise the total cost of overall systems, $\boldsymbol{x}$ is obtained by minimising the criterion function $cx$. Equation (8) expresses the solution $\boldsymbol{x}$, where the matrix B represents optimal basis of the minimisation problem.

$$x = B^{-1} f \tag{8}$$

We split matrix B into all processes involved and get Eq. (9)

$$\begin{aligned} x_j &= B_{j1}^{-1} f_1 + B_{j2}^{-1} f_2 + \cdots + B_{ji}^{-1} f_i + \cdots + B_{jn}^{-1} f_n \\ \frac{\partial x_j}{\partial f_i} &= B_{ji}^{-1} \end{aligned} \tag{9}$$

From Eqs. (9) and (6), it is possible to estimate outputs of Section K per unit of Demand I as shown in Eq. (10) .

$$\frac{\partial y_k}{\partial f_i} = \sum_{j=1}^{n} \left( E_{kj} \times B_{ji}^{-1} \right) \tag{10}$$

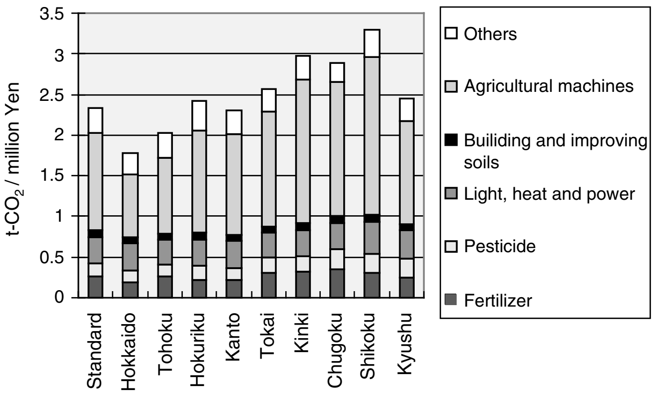


**Fig. 1** Regional $CO_2$ emissions related to rice production 1990 according to LCA

Thus it becomes possible to allocate resources or emissions to each product, even if a system includes recycling or multiple productions. This allocation principle is called BI allocation by Yoshioka et al. (1998).

In the following, we provide estimates for Japanese $CO_2$ emissions from rice production related to a value of one million yen. The average $CO_2$ emissions in 1990 of all products related to the value of one million yen were 2.39 tons (Japanese Government 2003). The average $CO_2$ emissions emitted in rice production were 2.33 ton $CO_2$ for a generated value of one million yen or 97.5% of average overall $CO_2$ emissions. More than half of this amount, 51.5% relates to agricultural machinery, followed by fuels and other energy (14.7%), fertilizer (11.0%) and pesticides (7.4%). Land consolidation works, indicated in Fig. 1 below as building and soil improvement, contributed 3.4%. All other categories within the LCA framework described by Yoshioka et al. (1998) were minor and contributed in total 12.9%. The Japanese data are described as standard in Fig. 1 below.

The 1990 gross agricultural output of 31,959 billion Yen is used to assess $CO_2$ emissions from total rice production. According to this calculation, 7,446,447 tons of $CO_2$ or 0.63% of the total GHG emissions is related to secondary emissions of rice production. Secondary and primary emissions together ($CO_2$, $CH_4$, $N_2O$) contributed 1.6% of Japanese GHG emissions in 1990.

## Regional variations within rice production

We had few local data of primary emissions based on previous Japanese research and it would be difficult to assess regional variations in a sophisticated way, due to this limited data. This is different for secondary emissions. Each Japanese prefecture produced economic input-output tables in 1990 according to the same scheme, so rice production and GHG emissions can be calculated for each prefecture of Japan using the method described above. In Fig. 1 we used the division into nine regional Japanese production units, each of them including one or several prefectures, structural data according to farm size, and also a calculation according to farm size units.

The regional variations ranged from 1.78 ton $CO_2$ in Hokkaido, the most Northern region, with the lowest emissions per one million yen to 3.29 ton $CO_2$ in Shikoku, the smallest of the four main islands, with the highest $CO_2$ emissions per one million yen.

With agricultural statistics based on structural differences associated with farm sizes, ranging from less than 0.5 ha to more than 5 ha, it became possible to calculate the conversion factors according to size structure. The regional and the farm size variations were not much different, as the structural pattern of farm size is closely correlated to the region under consideration. Hokkaido, the last region in Japan where rice was introduced, about 100 years ago, performs best. The average farm size is about 10 times larger here than in Shikoku. The number of farms producing this result is relatively small. The higher efficiency in resource use seems in particular related to machinery, which is 43.1% as compared to 59.4% in the Kinki region. In contrast, the share for fuel and energy is highest in Hokkaido with 18.5% and lowest in Kinki with 11.0% of $CO_2$ related emissions. The range of machines, despite a fairly low usage, is the best explanation for why small-scale rice production produces higher GHG emissions. In addition, small farms consume a higher proportion of the rice produced, not only for themselves but also for urban relatives, and less rice comes to the market. Oversupply with fertilizer and pesticides might additionally contribute to the high values.

## Variations in rice production in Japan since the 1960s

Between 1960 and 1990, the cultivated rice area decreased by one third. Rice supply decreased by one sixth as productivity increased by about 20%. The consecutive values for 1960 onwards in five-year steps are given in Table 3. The rice consumption was 118 kg and went down to 70 kg per person, a decrease of 40%, mainly due to the change in diet of Japanese people. However, the population increased during this time by 30% and the national demand decreased moderately. Labour productivity related to one hectare of rice was three times higher in 1990 than in 1960 and the number of farm households decreased by 30%. The increase in productivity was closely related to extensive resource use. According to calculations from Ahamer (2001) based on FAO data, energy demand increased by more than 20 times per unit area. This increase is closely related to the use of machinery, pesticides and fertilizer. Karube et al. (1995) describe the increase in the use of machinery during the above-mentioned period. From 1960 to 1970, primarily the number of walking tractors increased. From 1970 onwards, four-wheel tractors, rice transplanters and combined harvesters became frequent and in 1990, almost every farm had the full range of machinery including two trucks. Total fertilizer use, a combination of different kinds of fertilizers, increased by 40% from 1960 to 1990, but went down again after 1990, an indication that resource intensities might have slightly decreased after 1990.

**Table 3** Trends in Rice Japanese Rice Production 1960–2000

| Year | Cultivated land in ha | Cultivated paddy in ha | Rice supply in mill. tons | Average ha yield in kg*) | Consumption per person | Work hours per ha | Population in million**) | Farms in million | Total fertilizer per ha in kg | GJ/ha rice***) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1960 | 5323761 | 2943806 | 12.57 | 4270 | 118 | >1600 | 94.30 | 6.06 | 538 | <3 |
| 1965 | 5133831 | 2938632 | 13.35 | 4541 | 112 | 1412 | 99.21 | 5.66 | 630 | 4.5 |
| 1970 | 5156336 | 3010521 | 12.57 | 4175 | 95 | 1178 | 104.67 | 5.40 | 649 | 18 |
| 1975 | 4782518 | 2567260 | 12.71 | 4953 | 88 | 815 | 111.94 | 4.95 | 702 | 23 |
| 1980 | 4705587 | 2388826 | 11.12 | 4657 | 79 | 644 | 117.06 | 4.66 | 760 | 32 |
| 1985 | 4566859 | 2227661 | 11.19 | 5025 | 75 | 551 | 121.05 | 4.38 | 909 | 40 |
| 1990 | 4361168 | 1984127 | 10.56 | 5321 | 70 | 438 | 123.61 | 4.23 | 926 | 68 |
| 1995 | 4120279 | 2005234 | 10.78 | 5376 | 68 | 391 | 125.57 | 3.44 | 818 | – |
| 2000 | 3883943 | 1616334 | 9.49 | 5871 | 65 | 341 | 126.96 | 3.12 | 899 | – |

Sources: MAFF, Ministry of Agriculture, Forestry and Fisheries(2004). Statistics and Information Department, Minister's Secretariat, Census of Agriculture & Forestry

* Calculation: rice supply/cultivated paddy

** Statistics Bureau, Ministry of Health, Labour and Welfare; in Statistical Handbook of Japan 2003

*** G. Ahamer, Global Change Data Base, based on FAO data

After 1990, in the period relevant for the Kyoto protocol, most of the trends in rice production observed during 1960 and 1990 continued. The land under cultivation, the paddy area under cultivation, the total rice yield, the per capita consumption of rice, and the number of farm households decreased steadily. The reason for this development was the extraordinary progress in labour efficiency based on high resource inputs. In Table 3 those trends are expressed by the indicators work hours per ha and energy consumed per ha in GJ. Some trends, however, such as the use of fertilizers in rice production had a peak in 1990 and decreased again. Agricultural GDP went down, from 4.16 in 1970 to 1.71 percent in 1990, and in 2000 it was only 1.07 percent. This implies that less money is now available for agricultural machinery, fertilizers, pesticides and improvement of agricultural land. More than 20% of the paddy area was not cultivated in 2000. The figures indicate that rice production was and still is changing very fast.

In accordance with the best practice advice, we estimate the change in GHG emissions of rice production for the years 1990, 1995, 1999, 2000 and 2001 in Table 4. We calculate $CO_2$ ourselves, use the official rice-related value for $CH_4$ (Japanese Government 2003) and adopt the $N_2O$ value for agricultural soils with the ratio cultivated rice area and cultivated total agricultural area.

Secondary emissions should in principle be assessed in the same way as in 1990 by the LCA calculation we presented above. However, we did not have the necessary data. Therefore we estimated figures according to: (a) the value of rice production in the respective year (Statistical Division, Ministry of Agriculture, Forestry and Fisheries, 2003), (b) the results of regional variations of LCA in 1990 provided in Fig. 1 above and (c) the trends in time of Table 3. Almost 20% of the rice area cultivated in 1990 was not cultivated in 2000. We assume that more difficult and mountainous smaller areas were taken out of production, while the larger more profitable areas are still in place. The standard value has therefore dropped from 2.33 ton in 1990 to perhaps 2 ton per one million yen rice value in 2000, about the same value as the region Tohoku in 1990. In Table 4, we provide the percentages of the three main greenhouse gases.

## Outlook and discussion:

The significance of rice production in Japanese GHG emissions decreased and will further decrease until the period 2008–2012. The shares in GHG emissions in 1990 and 2001 were 1.6% and 1.05% respectively. If we assume that the

**Table 4** Share primary and secondary emissions in rice production 1990–2001

| Year | Rice value in 10 billion Yen | Tons $CO_2$/ mill. Yen | Mill. tons $CO_2$ | Share GHGs | $CH_4$ rice mill. tons $CO_2$ | Share GHGs | $N_2O$ agricultural soils | Cultivated rice/ cultivated soil | $N_2O$ rice mill. tons $CO_2$ | Share GHGs |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 3.196 | 2.33 | 7446.68 | 0.63% | 7075.73 | 0.60% | 9746.46 | 45.50% | 4434.2 | 0.37% |
| 1995 | 3.186 | 2.2 | 7009.2 | 0.53% | 7200.86 | 0.54% | 8797.91 | 48.67% | 4281.7 | 0.32% |
| 1999 | 2.376 | 2 | 4752 | 0.36% | 6165.26 | 0.47% | 8151.76 | 41.62% | 3392.4 | 0.26% |
| 2000 | 2.321 | 2 | 4642 | 0.35% | 6018.51 | 0.45% | 8144.45 | 41.62% | 3389.4 | 0.26% |
| 2001 | 2.220 | 2 | 4440 | 0.34% | 5907.16 | 0.45% | 8136 | 41.62% | 3385.9 | 0.26% |

Source: Statistics Bureau, Ministry of Health, Labour and Welfare 2004, Gross Agricultural Output and Agricultural Income Produced (1985–2001) and Ministry of Environment 2003, National GHGs Inventory Report of JAPAN and own calculations ongoing trends continue, a value of 0.7% in 2012 is likely. Even in absolute numbers, we see that the emissions related to rice production have decreased by 28% from 1990 to 2001. But should one be happy that rice is contributing in an extraordinary way to the reduction of Japanese GHGs? Some governmental strategies aimed to solve the problems of agricultural subsidies and the fulfilment of the Kyoto protocol requirements simultaneously. We consider this to be impossible. As shown in Table 2 and Table 4, the Japanese GHG emissions increased during the same period as rice-related emissions decreased. Rice production contributes to both, to mitigation of global warming and to the adaptation to the probable consequences of climate changes.

GHG emissions of rice production were particularly high in 1990. No other rice producing country exceeded the intensity of Japanese rice production. Regarding the resource performance of rice production in 1990, many farms in Japan were to have been closed and production was to have shifted abroad. And indeed, both happened, many farms were closing and according to international trade agreements, Japan had to open its market to foreign rice imports. There is a close dependence between the industrial sector and the related service sectors. In the GHG emission inventory, the share of agricultural industries went down, but to a considerably lower percentage, an indication that the loss of domestic markets is partly compensated for by increasing exports. Sewerage previously used as a nutrient base for rice production resulted in ever more sewage sludge that had to be incinerated. And indeed, we observed a sharp increase in GHG emissions in the waste sector (see Table 2). If rice is not produced locally, more freight traffic and transportation is required (Ministry of Environment 2003); GHG emissions in this sector increased sharply. Yokohari et al. (1996) pointed out that paddy fields in the non-mountainous urban areas have an important cooling task in summer. Thereby, the amount of energy used for air conditioning can be significantly reduced. The increase in GHG emissions in the domestic sector during 1990 to 2001 is a reason to highlight this function of paddy as well. In summary, the benefit of having less GHG emissions in rice production is offset by the increase in other sectors. A further decline in rice production is likely to be relative to an increase in total GHG emissions.

Other important benefits of rice production are water management, disaster prevention, landscape preservation, and biodiversity conservation. It is necessary that rural areas remain populated and that rice production continues. A retreat of humans from marginally suitable paddy and rural lands (MAFF 2003) will have many more consequences than just the loss of rice, which could be imported. A unique cultural landscape developed over 1,500 years with particular plant and animal species is endangered. Recent Japanese research (Fukamachi et al. 2002; Takeuchi et al. 2003) shows that, until a few decades ago, forestland and rice fields were a combined system of nutrient supply to rice production and proper management of forests. Secondary biotopes dependent on the particular use of land could develop here. In the case of Japan, two thirds of all water used in Japan is consumed by agriculture, primarily for irrigation of paddy-fields. Dams constructed for rice production slow down the flow of water in mountains and buffer the consequences of extreme weather events that are expected to increase in the future. The maintenance of ponds and irrigation systems will become inadequate. Rice plants fix cultivated field soil during typhoon periods in September. If rice is abandoned, erosion plots can emerge easily if the soil is left bare with nothing to alleviate the disturbance on land. Starting points for disasters may be created and unwanted impacts of torrents, flooding and hang slides will occur more frequently. This in turn may cause damage to urban regions at a later stage.

The pressure on high inputs will decrease with a change from a production-based, to an area- based or direct farmer support system. Currently some 500,000 farm households or one out of six actively take part in reducing the amount of chemical fertilizer and other agricultural chemicals (MAFF 2001). During 1999 and 2000, several new laws were passed, such as “The Law Concerning the Promotion of a Highly Sustainable Agricultural Production Method” and “The Law Amending Several Provisions of the Law Concerning Standardization and Proper Labelling of Agricultural and Forestry Products” and have recently been implemented. Food security and food supply will remain a task of international co-operation and cannot be solved within Japan. While the domestic supply of rice still covers more than 100%, the total agricultural self-sufficiency is only 40% of the energy content of nutrition (Statistical Handbook of Japan 2003) and it is desirable to achieve a higher percentage with less resource input.

## Conclusions

We no longer have mere rice production, but a sophisticated resource-intensive land management system based on rice cultivation and multipurpose agriculture. It is adapted to the available intensities of current resource flows, but the resource flow continues to change. There might be more competition for fewer resources in future. Japan can become an example on how a less resource-demanding rice production can be facilitated.

Solutions that try to mitigate global warming and to reduce GHG emissions, but disregard the dependencies between agriculture and other sectors are likely to fail. The observed reduction of GHG emissions from rice production is in this context a minor success, because the emissions in other sectors increased simultaneously and are likely to increase with a further decline in rice production.

Overproduction is no longer economically favourable and one can expect that ever more farm households will reduce their inputs to rice production. The challenge is to transform the system of rice production into an ecologically sound one, and to keep the services related to rice production at a lower environmental cost. This includes any link in the chain of inputs, starting from the construction of paddy-fields, to the cooperative use of agricultural machinery, fertilizers, pesticides and fuels. In particular the combined use of machinery can further reduce rice emissions.

**Acknowledgements** The authors thank Prof. Ryuji Matsuhashi, University of Tokyo, Graduate School for Frontier Sciences, for providing the data of the LCA analysis. We thank Prof. Kevin Stafford, Massey University New Zealand, for his comments and suggestions. We are grateful to Christian and Sylvia Idström for proofreading the manuscript. Further, we express gratitude to the University of Tokyo, Graduate School for Agriculture and Life Sciences for inviting one of the authors during fiscal year 2003 and to make this research possible.

## References

Ahamer G (2001) A Structured Basket of Models for Global Change. In: Rautenstrauch C, Patig S (eds) Environmental Information Systems in Industry and Public Administration (EnvIS), Idea Group Publishing, USA, pp.101–136

Breiling M, Hoshino T Matsuhashi R (1999) Contributions of Rice Production to Japanese Greenhouse Gas Emissions applying LCA in Rice Production as a Methodology. KEIO Discussion Paper No. 38 WG-2-16, Tokyo, 31 p

Fukamachi K, Oku H, Nakashizuka T (2002) The change of a satoyama landscape and its causality in Kamiseya, Kyoto Prefecture, Japan between 1970 and 1995. Landscape Ecology 16: pp. 703–717

IPCC/UNEP/OECD/IEA (1997) Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual. 4.3. Methane Emissions from Rice Cultivation: Flooded Rice Fields. Reference Manual pp. 4.53–4.71

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. $CH_4$ from rice agriculture. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Kanagawa, Japan. pp. 399–417

Karube J, Haegawa S, Toyomitsu Y Adachi K, Tada A (1995) Basic Aspects of Paddy Fields. In: Tabuchi T, Hasegawa S (eds) Paddy Fields in the World. Editors on behalf of Japanese Society of Irrigation, Drainage and Reclamation Engineering (JSIDRE), Tokyo, pp. 247–268

Ministry of Agriculture, Forestry and Fisheries (2001) Annual Report on Food, Agriculture and Rural Areas in Japan FY 2000, Summary, pp. 49

MAFF Ministry of Agriculture, Forestry and Fisheries (2003) Annual Report on Food, Agriculture and Rural Areas in Japan FY 2002, Summary, Chapter 3, Creating a Recycling Based Society and Beautiful Rural Areas, pp. 47–57

MAFF Ministry of Agriculture, Forestry and Fisheries (2004) Statistics and Information Department, Minister's Secretariat, Census of Agriculture & Forestry. Available online: http://www.tdb.maff.go.jp/toukei/toukei

Ministry of Environment (2003) National GHGs Inventory Report of Japan, pp. 2.1–2.22

National Institute of Population and Social Security Research (2002) Population Projections for Japan 2001–2050. pp. 1–4

Neue H (1993) Methane emission from rice fields: Wetland rice fields may make a major contribution to global warming. BioScience 43(7):4 pp. 66–73

Sass RL, Fisher FM, Ding A, Huang Y (1999) Exchange of Methane from Rice Fields: National, Regional, and Global Budgets. J Geophysi Resh, Atmos 104(1999) pp. 26943–26952

Statistics Bureau, Ministry of Health, Labour and Welfare (2003) Statistical Handbook of Japan 2003. Chapter 5, Agriculture, Forestry and Fisheries, pp. 57–63

Statistics Bureau, Ministry of Health, Labour and Welfare (2004) Gross Agricultural Output and Agricultural Income Produced (1985–2001) Link: http://www.stat.go.jp/data/nenkan/zuhyou/y0724000.xls

Tsuruta H (2002) Methane and nitrous oxide emissions from rice paddy fields. Proceedings of the 17th World Congress of the International Society of Soil Sciences in Bangkok. http://www.sfst.org/Proceedings/17WCSS_CD/papers/2100.pdf

Takeuchi K, Brown RD, Washitani I, Tsunekawa A, Yokohari M (eds)(2003) Satoyama: The Traditional Rural Landscape of Japan. Springer, Tokyo

Wassmann R, Lantin S, Neue HU (2000) Methane Emissions from Major Rice Ecosystems in Asia. Develop Plant and Soil Sci 91 pp. 1–36

Yagi K, Tsuruta H (1994) Reducing Methane Emission from Rice Cultivation. Proceedings of the international workshop on Sustainable Agriculture and the Conservation of Agro-Ecosystems, pp. 221–225

Yagi K, Minami K (1998) Methane Emissions from Paddy Fields as affected by soil properties and its implications to the global estimation, paper presented at IRRI-UNDP Final Workshop, Int Rice Research Institute, Beijing, China, pp. 34–38

Yokohari M, Brown RD, Kato Y, Moriyama H (1996) Effects of Paddy Fields on Summertime Air Surface Temperatures in Urban Fringe of Tokyo, Japan. Landscape and Urban Planning 38(1–2) pp. 1–11

Yoshioka M, Matsuhashi R, Ishitani H (1998) Study on methodology for life cycle assessment using related process model. Int J Global Ener Issu 11(1–4): pp. 104–110