Contributions of Rice Production to Japanese Greenhouse Gas Emissions applying Life Cycle Assessment as a Methodology

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Abstract

The paper focuses on rice production and the environmental challenges connected with rice production. In particular we exemplify the role of rice in the possible reduction of Japanese greenhouse gas emissions applying Life Cycle Assessment as a methodology. Rice is the most important agricultural commodity in Japan and Japan has an overproduction of rice. The problem of reducing the amount of rice has two practical background considerations.

i) It is expensive to support overproduction and

ii) The overproduction causes unnecessary environmental pollution.

We are in particular interested in the second aspect, which is in fact closely related to the first one. A practical background for the analysis is the intended reduction of greenhouse gases expressed by the Japanese government. During the COP3 event of December 1997 in Kyoto, Japan obliged itself to reduce greenhouse gas emissions by 6% relative to 1990 levels until the period 2008 to 2012. Agricultural production should sign responsible for a great part of this reduction. We want to show the potential of reducing CO_2 in rice production by a life cycle assessment approach (LCA).

LCA became a standard of Japanese industry in 1997. Hitherto LCA is not a common methodology in the field of agriculture. However, a lot of environment related discussions in the agricultural sector could also be discussed on base of an LCA assessment. LCA assessments are supposed to give valuable information of pollution loads in agriculture and their possible reduction. Today, there are many different LCA methods available.

There are two principle approaches, the bottom up approach and the top down approach. At the bottom up approach information is collected at the source of origin, namely the different locations of production. In the case of rice we have more than 3 million producers in Japan, which requires many samples to get a representative picture from this approach. The top down approach, related to macro-economic modelling, allows assessing the problem quickly and is based on economic input output tables. The top down approach is only suitable for major pollutants. It is a suitable approach to assess the global warming potential, but it can not adequate information concerning many pollutants covered in a bottom up approach. According to the availability of data, we first provide a top down approach, which we document in this paper. Later on we intend to complete with a bottom up approach.
In the first part of this paper, we will look at rice production from different viewpoints. First from the viewpoint of producers, second from the viewpoint of consumers and third from the viewpoint of environment and resource use. As the three views are related to entire Japan, we provide additional information concerning rice production regions in Japan and concerning structural patterns. In the second part of this paper, we describe first our LCA approach and its principles related to sustainability. Second we perform calculations concerning the average Japanese CO_2 emissions related to rice and third we differentiate this average according to regions and structural factors.

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Work Group2

1. Introduction

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2. Rice Production in Japan

2.1 Historical Overview and Recent Trends of Rice Production in Japan

Since about 1700 years rice is produced in Japan. Rice cultivation was brought from China, via Korea to Japan. Soon rice became the major basis of food consumption. Rice availability allowed a more dense settlement structure of Japan as a sophisticated system based on feudal land lords and local resource use was established and improved. Japanese culture developed along with rice production. Rice was a decisive factor in the Japanese political system as power was closely related to the access of food. After a period of civil wars the Edo period lasting from 1603 to 1867 brought peace and more control over land resources. Thereby improvements in rice production could take place. This improvements were based on increased labour intensity. Imports of resources outside Japan was not possible, as during the Edo period the country was closed to the outside world.

The Meiji period following the Edo period (1867 to 1912) and the Taisho lasting until 1926 and current Showa period led gradually to a new situation. The cities where rapidly modernised and increased in size. There was a strong demand on labour power from rural areas, the lack of working power was compensated by new, sophisticated agricultural methods combined with the access to imported resources. After World War II, in 1948 land reforms took place, the old feudal system was destroyed and individual farmers got access to own land. The current small scale size of Japanese farms is a result of those land reforms.

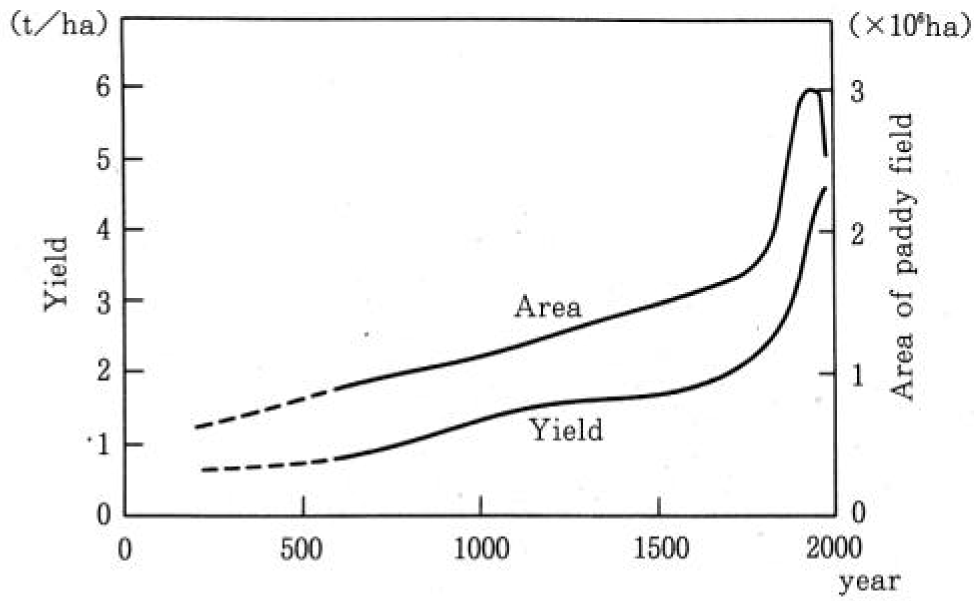

Figure 1 Historical development of rice production area and rice yield.

Source: S. Hasegawa, T. Tabuchi (1995) and H. Fukuda et al. (1984)

Better methods in land management allowed to increase rice yields from some 500kg at the beginning of rice cultivation in Japan (around the year 300) to up to 5000kg per hectare in recent decades. The land devoted to rice production increased from about 1% of land area at the beginning of rice cultivation (around 300) to 10 % around 1980, but decreased again to 7%, the current level. The population development was closely related to rice production. It increased from less than 5 million in 300 (estimate based on availability of rice and land) to 126 million at the end of the 20th century. Just in recent decades population development became independent from rice production.

2.2 Recent Trends in Rice Production

The situation of rice production changed significantly after the last world war. Over production was reported for 1970s the first time in history, but other economic activities became more important than rice production. They gave the income that rice production could be increasingly more industrialised. The economic importance of rice production fell from 9% in 1960 to 1.8% in 1990. At current Japan is the 8th

important rice producing country and accounts for 2.2% of world rice production (1997). Production costs are significantly higher than in any other country of the world and about 8 times higher than in the US.

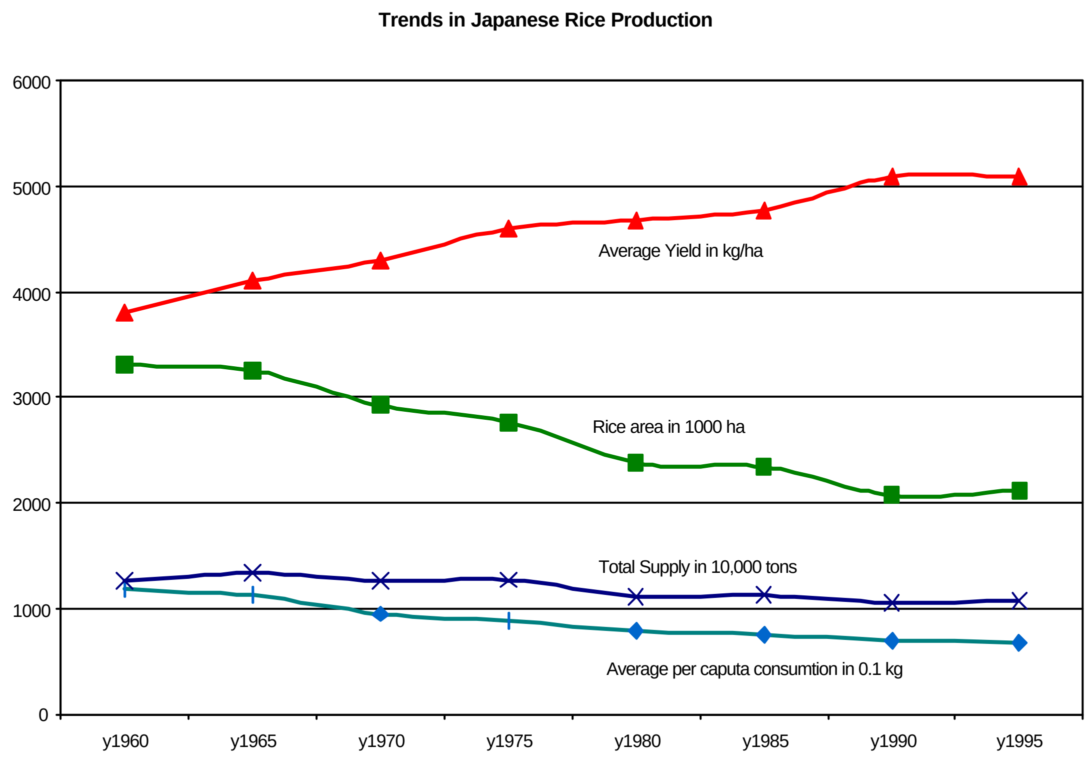

Figure 2 Recent trends in rice production

Source: Agricultural Census

During the period 1960 and 1995, the average yield of rice increased from less than 4,000 kg rice production to more than 5,000 kg rice production. The rice area decreased during the same period about one third from more than 3 million hectare to slightly more than 2 million hectare. The total rice supply decreased from 12 million tons to close to 10 million tons. The average consumption per capita decreased from 118 kg per capita to 68 kg per capita. As the population increased in average by almost one million a year, from 93 million in 1960 to 125 million in 1995, the reduction of the per capita rice consumption could be balanced by the increase of population.

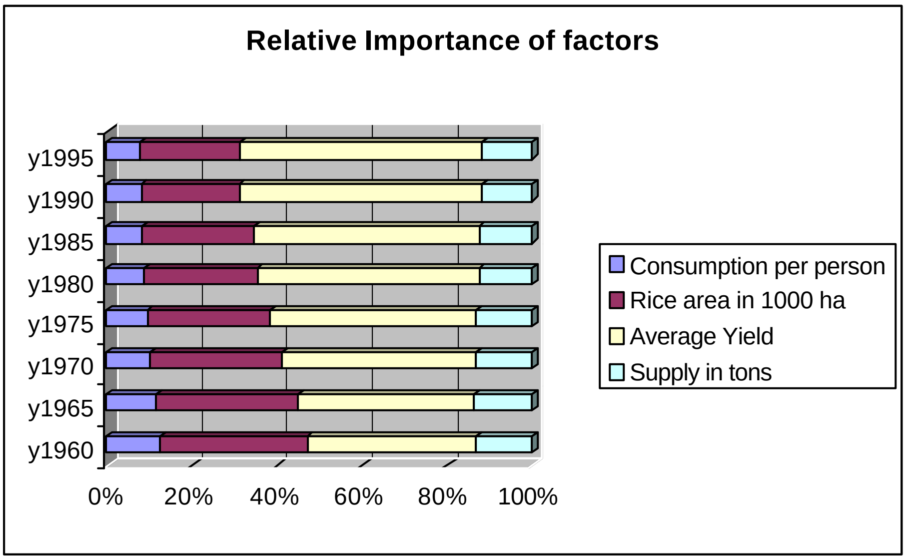

Figure 3 Ratio Between Factor Importance

The picture showed that the factor yield became more important, while the factor land and consumption per person became less important and factor supply decreased slightly in importance. Emphasis was increasingly more given to high yields and not to maintain land under cultivation. The consumers did not request any longer after rice as they did in previous time as they could compensate rice by other food. Rice supply could remain relatively stable, as the decrease in per capita demand was accompanied by population increase.

2.3 Supply Related Factors of Rice Production

Agricultural production depending on local resources was for long time the major limitation of Japanese population growth. Today food imports allow to have a high population density, that would not be possible, if the country would be closed. Only in the case of rice there is self sufficiency which is also dependent on the import of resources outside Japan. Rice has nevertheless an important function to secure food availability within the country and to occupy people in rural areas.

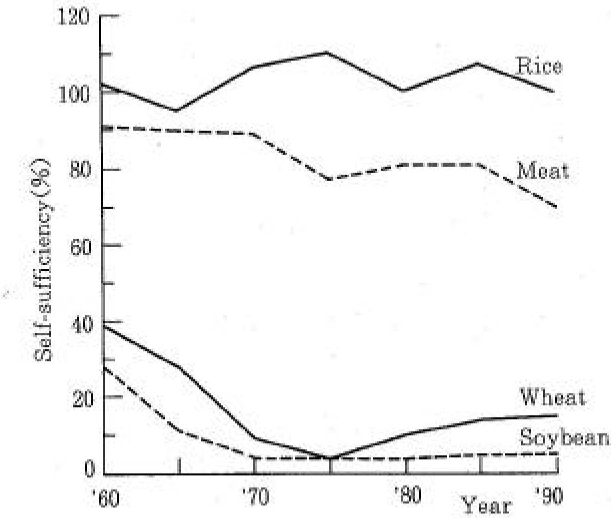

Figure 4 Most Important Agricultural Products and Self Sufficiency within Japan

In most other agricultural commodities we have a domestic shortage. As there is over production of rice, a shift to other agricultural commodities is wanted. This plan is not easy to follow as in particular paddy fields require investments before rice production, that are not necessary for many other agricultural commodities.

2.4 Population trends in Rice Production

There are about 3.5 million rice producers in Japan. At the beginning of the 60s there were almost 12 million rice producers in Japan. In fact the younger farmers of those days are still active and the average age of rice farmers increases. There are 3 usual patterns related to population trends. Remaining colleagues overtake from those finishing with rice production. It is common to take another job and rice production and get a the second income that is higher. Young people migrate out of the rural areas. The question how long this trends can continue and who will take over in the future is unsolved. Old rice farmers live further with the experience of famine and food shortage of several decades ago, where the aim was to obtain self sufficiency in rice production, but they have more sophisticated means to produce rice.

Table 1 Share of Agricultural Households Against Others (in 1000)

Number Households	*Total*	*Agricultural*	*Mixed Agricultural*	*Non Agricultural*	*No workers*
1980	35824	1360	2131	28972	3311
1985	37980	1210	1954	30400	4344
1990	40670	993	1596	32568	5357
1995	43900	935	1379	34464	6902

Source: Japan Statistical Yearbook 1998, National Census data

Within 15 years from 1980 to 1995 the number of agricultural households went down from 3.5 million households to 2.3 million. The number of farm households was reduced by one third. On the other hand the number of total households increased considerably and the number of people per household decreases.

Table 2 Share of Full Time and Part Time Farm Households 1960 to 1995 (in 1000)

Number Households	*Total*	*Full time*	*Part time*
1960	6057	2078	3979
1965	5665	1219	4446
1970	5342	831	4510
1975	4953	616	4337
1980	4661	623	4038
1985	4376	626	3750
1990	3835	592	3243
1995	2651	428	2224

Source: Japan Statistical Yearbook 1998, Agricultural Census data

Within 35 years the number of farm household decreased sharply to 44% of the value from 1960. The number of part time farms decreases considerably less (to 56% compared to 1960) than the full time farms (to 21% compared to 1960).

Table 3 Income Source of Agricultural Households

Year	*Agricultural Income*	*Non Agricultural Income*	*Total*	*Share of agricultural income*
1965	365	396	761	48%
1970	508	885	1393	36%
1975	1146	2268	3414	34%
1980	952	3563	4515	21%
1985	1066	4437	5503	19%
1990	1163	5438	6601	18%
1995	1442	5453	6895	21%

Source: Asahi Shinbun 1999, Agricultural Census data

Table 4 Occupation in Agriculture (in 10,000)

Farm Occupants in 10.000	*total*	*female*	*Share of female*
t1965	1152	695	60%
t1970	1025	628	61%
t1975	791	493	62%
t1980	697	429	62%
t1985	636	388	61%
t1990	565	340	60%
t1995	490	286	58%

The decline of farm households is most obvious in the youngest age group, where within 20 years the number of households reduced to less than 25%. Large is also the reduction in the medium age group 30 to 59 years old where the number reduced to less than half in two decades. The only group that remained stable and even slightly increased was the number of farmers of 60 years and over. As we had relatively old data from 15 years ago for our disposal we expect the oldest group to be the largest one at the current situation, approximately the same in number but considerably less farms in the youngest and the middle age group.

The pattern of full time farm household shows women as more important. This could be explained by the fact, that the husband is working outside the farm, in particular in the age group 30 to 59. With becoming 60 the husbands return home, so the distribution between sexes becomes more equal.

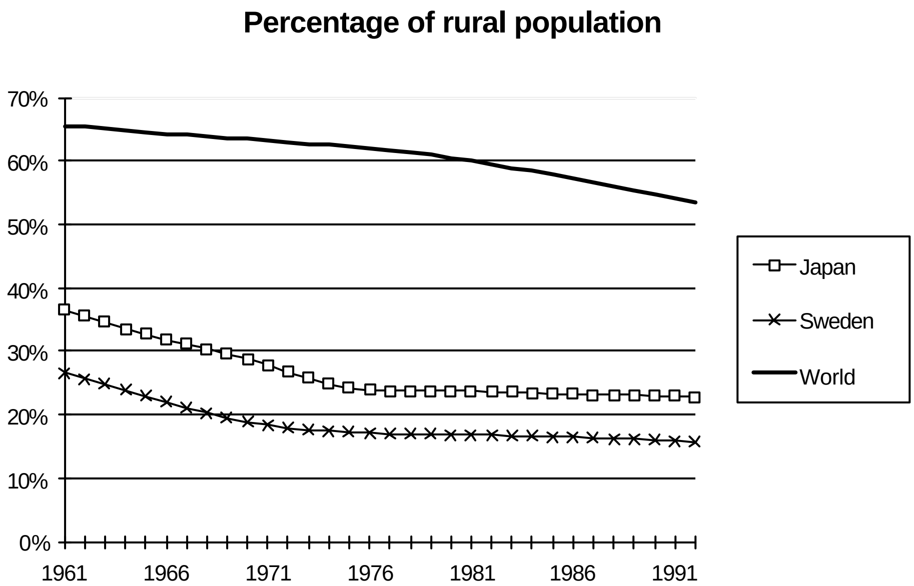

Figure 5 Decrease of Rural Population in Japan

Source: G. Ahamer, Global Change Data Base (1995)

People live ever more dense than what they lived before. The rural population would be even less, if people would not commute over long distances. A rural area is considered an area with less than 2,000 people living in 1 km². In addition table 4 explains that the rural population is getting older.

2.5 Labour Intensity in Rice Production

In this figure we see the trend concerning rice yields and labour intensity during the last decades. Currently some 400 hours of human labour or one fifth of what was usual only 40 years ago are spent for the cultivation of one ha of rice. The rice yield increased from 2 tons per ha to more than 4 t per ha. So the farmer get more than 10 times the yield per working hour than just few decades ago.

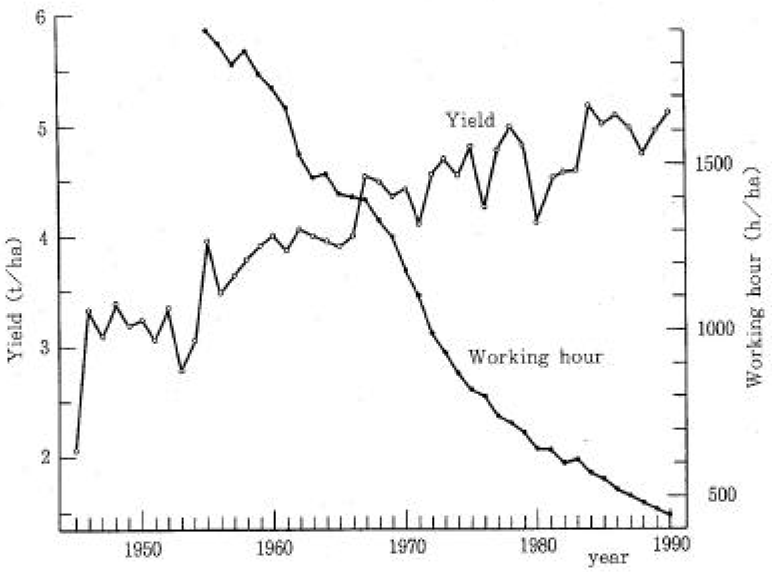

Figure 6 Decrease of Labour Intensity in Rice Production

Rice cultivation and industrial activity supported each other. Industry gave means in the form of advanced agricultural machinery and chemical inputs to reduce the labour time and rural areas gave labour force to the industry.

At current almost all young labour force has migrated from rural areas. But the remaining people staying on the country side are important from the view point of customers to industry. In the following figure we find some information about the role of farmers as consumers of industrial products.

Table 5 Importance of farmers as customers of agricultural machinery (1990)

	Average agricultural machines of 100 farm households
Generator	2
Engine	4
Pump	11
Tractor(20ps<)	36
Tractor(20ps-50ps)	47
Tractor(50ps>)	2
Nursery Warmer	8
Hand Tractor	57
Transplanter(2 raw)	31
Transplanter(3-5 raw)	41
Transplanter(6 raw>)	7
Sprayer	28
Powder Sprayer	23
Binder	29
combine(3 raw<)	50
combine(4 raw>)	6
Threshing	23
Hulls remover	40
Dryer	53
Truck	198

Source: Agricultural Census 1990

One can see that farmers are by far more important as consumers of industry than the urban population. It is further clear that farmers could not effort this level of mechanisation if there would not be agricultural subsidies. Farmers support is also support for the industry as well. Regardless the size of the farm, the prestige of the farmer demands for a complete set of agricultural machinery.

2.6 Demand Side of Rice Production in Japan

In Japan one can observe a change in the diet. The traditional rice diet is based on carbohydrates and is increasingly "westernised" with higher levels of fat (Vermeul 1996). From 1951 to 1988, the ratio of carbohydrates decreased from 78% to 59%. This is still about a 15% higher carbohydrate intake as compared to Western countries like France, UK, US, Germany or Italy with a share between 41% and 46% carbohydrate. Fat increased from 10% to 28% in the same period and proteins remained stable at 13%.

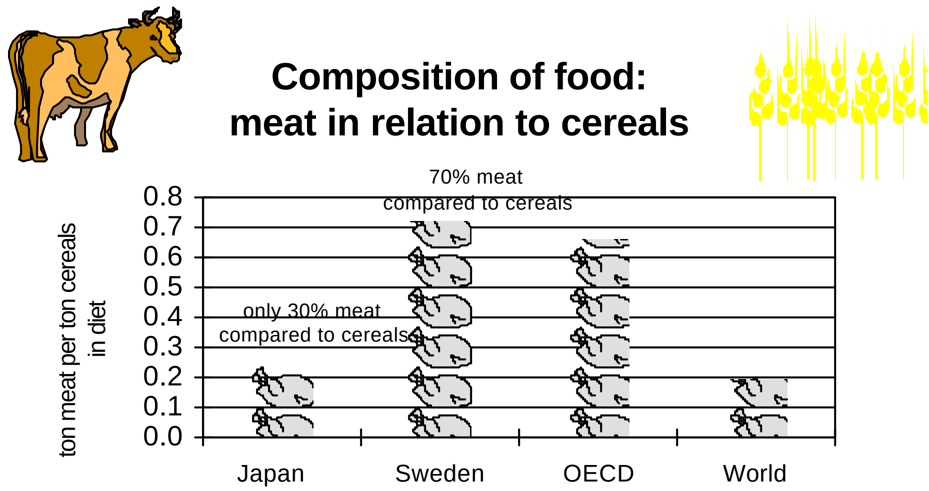

Figure 7 Comparison of Diet based on Rice and Cereals in Japan to Other Countries

Source: G. Ahamer, Global Change Data Base (1995)

Meat consumption was still low in Japan (1991) as compared to other wealthy countries, but higher than the global average. The trend is in favour of more meat consumption at the expense of rice. The difference to the OECD average may become considerably smaller over the next decades.

During 1960 and 1995 the average rice consumption decreased from 118kg to 68kg per capita (see fig.2). This means a decrease by 42%. As the population increase during the same time was 34%, the decrease in rice consumption was considerably smoothed. However, assuming that population development will stabilise, one may experience a more drastic decrease in rice demand with strong effects for the producers.

Another question is certainly the readiness of taxpayers to continue the support for agriculture and in particular for rice farming causing the highest costs. So are rice production costs 8 times higher than in US or in Thailand. The group that supports the government policy to support rice farming is getting smaller and the shrinking number of farm households is the reason for a more difficult situation for the remaining farmers. So it is clear that rice producers are challenged in the future to produce cheaper and to combine rice production with other services required by the urban population. This has also to include a more benign attitude towards environment and a higher resource efficiency of Japanese rice production. The close interaction of agriculture and industry both profiting from the agricultural support system will be increasingly constrained by overall economic and environmental considerations.

2.7 Environment and Resources Side

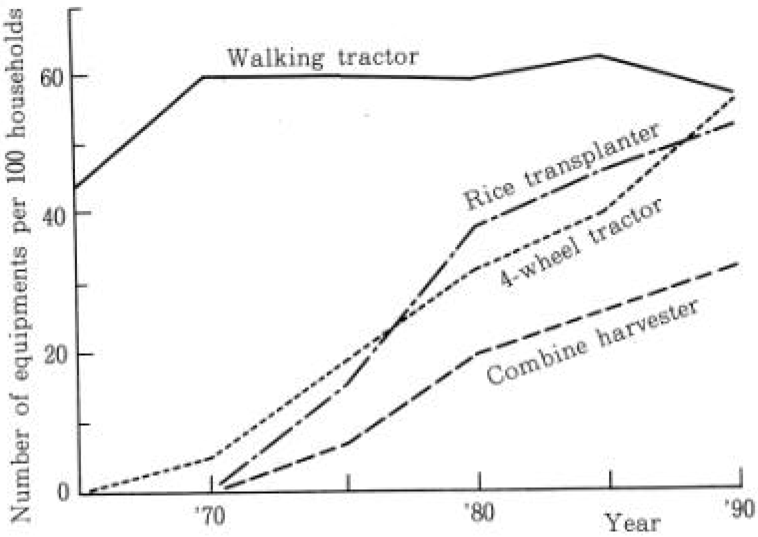

Figure 8 Increase of Agricultural Machinery (1950 to 1990)

In 1965 only every second household had one simple tractor, in 1990 every farm household had a tractor, about half of them even a more advanced 4-wheel tractor. Rice transplanters were introduced in 1970, in 1990 every second household had a rice transplanter. Combine harvesters were introduced in 1970 as well and some 25% of farm households bought such a machine. Those are primarily the large farmers.

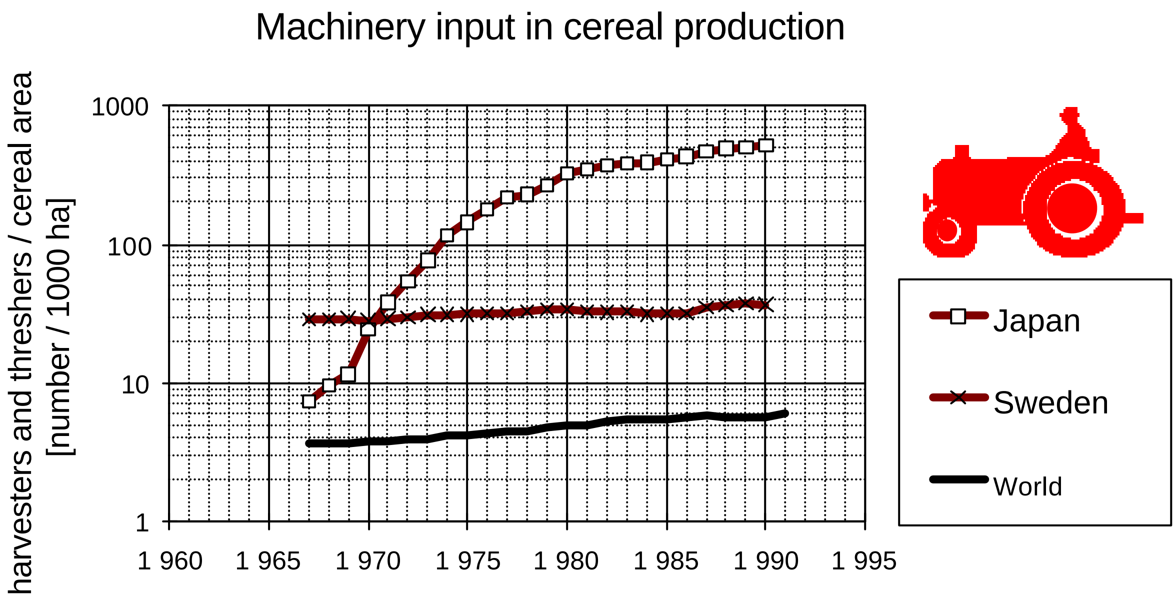

Figure 9 Increase of Agricultural Machinery per Hectare 1967 to 1990

Source: G. Ahamer, Global Change Data Base (1995)

2.8 Increase of Resource Inputs 1961 to 1990

The success in yield increases and labour productivity was only possible due to a strong increase of production inputs. Here we quantify these inputs based on fertiliser use and on energy consumed for rice production related to one hectare of land.

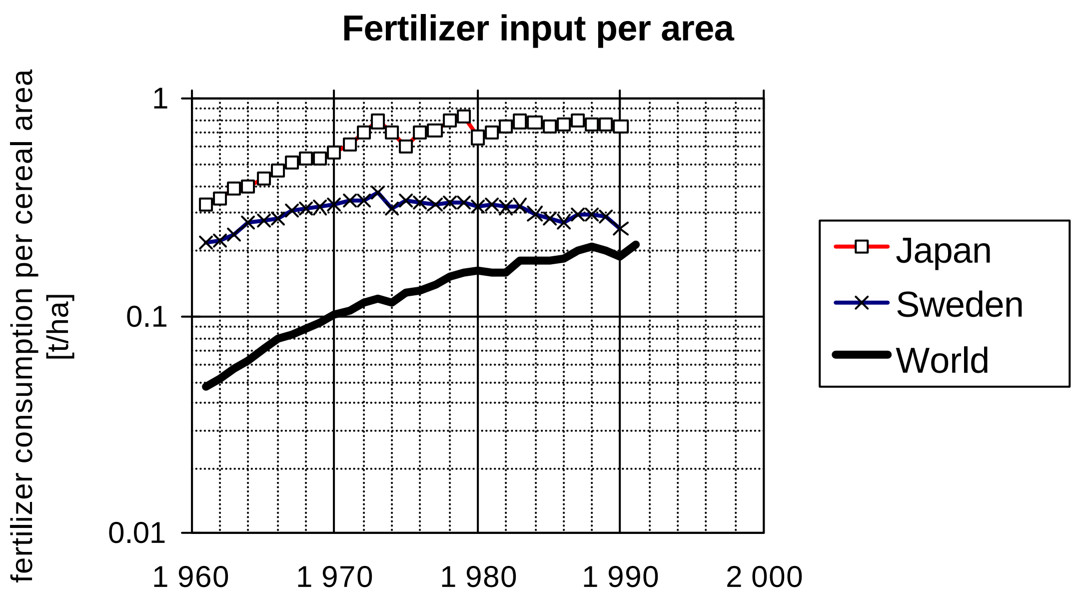

Figure 10: Increase of Fertiliser 1961 to 1991

Source: G. Ahamer Global Change Data Base (1995)

The amount of fertiliser use increased from 200kg in 1961 to less than 800kg in 1990. In 1979 the fertiliser use had the peak with about 850kg, but stabilised under this level during the 80s. In the global picture, Japan lies 8 times over average.

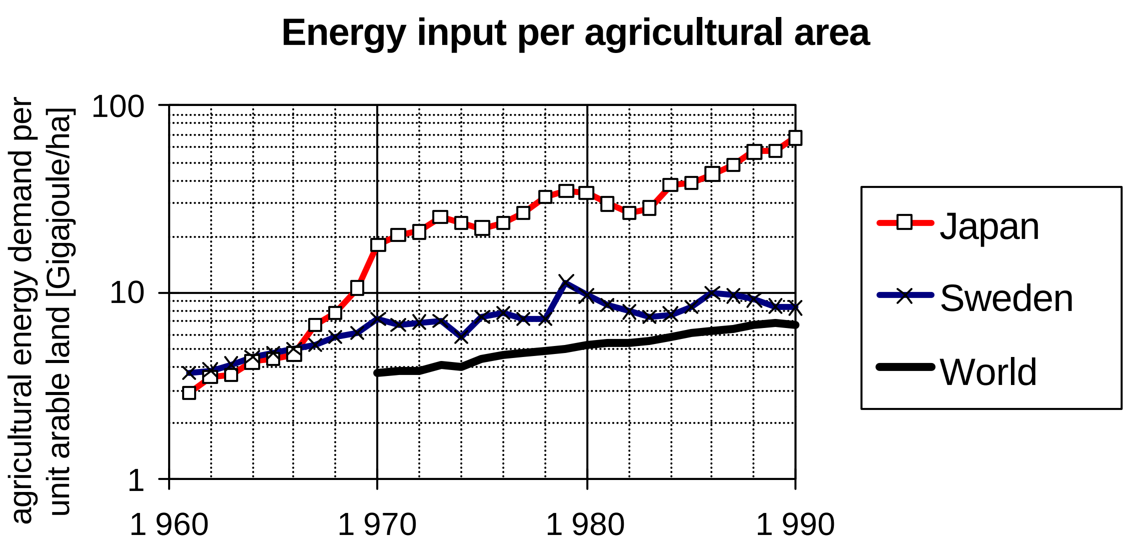

Figure 11 Increase of Energy Use per Unit Rise 1961 to 1991

Source: G. Ahamer Global Change Data Base (1995)

Combining the energy input of different inputs necessary to produce rice we see an impressive increase. The energy requirement rose from 2 GJ per hectare to 70 GJ per hectare or some 35 times during the observation period 1961 to 1991.

2.9 Marginalisation of Land and Change of Land Use

During 1960 and 1995, in particular during 1970 and 1990 the rice area was reduced. One third of the rice fields were abandoned. While the load of chemicals was considerably less in these areas, they experienced different problems.

In many cases there was no planned transition and because of this, many problems come into existence. For example rice terraces in hilly areas, difficult to cultivate were the first to be given up. Thereby a unique cultural landscape is disappearing. If not planted with forest, it is likely that these terraces can become easily destroyed during typhoon periods and soil that is usually fixed by rice plants during the most intensive typhoon month September erodes much more easy. Erosion plots can become initial points for a future disaster in connection with hang slides.

It is however difficult to find more precise numbers for the magnitude of this problem and other similar problems connected with a sudden retreat of humans from marginally suitable agricultural land. The problems of marginalisation are further no short term problems, but require a response in a 10 to 20 years perspective. Parts of the funds used for the agricultural support system have to be shifted from rice to this purpose.

2.10 Regional Differences in Japanese Rice Production

In the following we give some brief information about different Japanese areas and their suitability for rice production. Measures to optimise the economic, environmental and social performance of a more sustainable rice production in Japan are not unique all over Japan, but require particular concern for regional and local differences. We find most of the rice fields in rain fed low lands up to an altitude of 500m. Mountain rice, which is not dependent on irrigation, is relatively small in number and accounts only for a few percent.

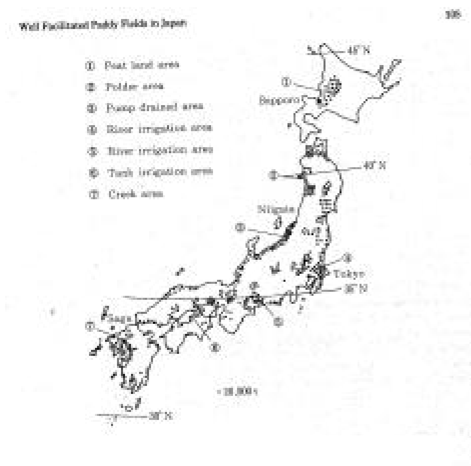

Figure 12 Most Important Rice Production Areas in Japan

There are many varieties of rice adapted to different regions. As with any other product some give high yield and lower quality and others lower yield with high quality. This is also reflected in the rice price, where high quality rice can cost up to two times the price of lower quality Japanese rice varieties.

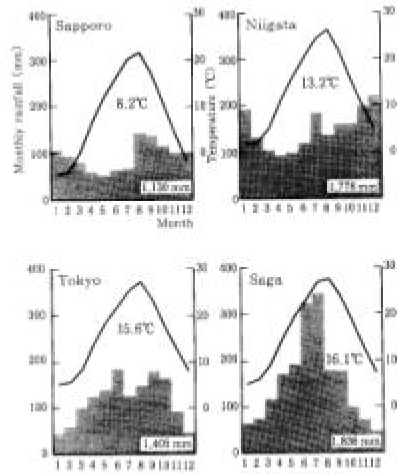

Figure 1 Temperature and precipitation in four cities
(Source: Japan National Astronomical Observatory, 1993)

Figure 13 Differences in Climate Conditions Within Japan

There are considerable climate differences within Japan. While in Sapporo the annual mean temperature is 8.2°C, Saga is in average with 16.1°C almost 8 degrees warmer. This will have primarily an influence on the choice of rice variety. In hotter areas the use of pesticides is expected to be higher in colder areas we would expect lower yields per production area.

Table 6 Differences in Rice Production in Major Japanese Regions (1990)

	Farming Household		*Paddy Field*			
	Total	Full Time	Area (ha)	Average Area (ha)	Area km²	Percentage of Paddy
Hokkaido	95437	42582	244247	2.559	78520	3.11
Tohoku	607433	59206	622589	1.025	66906	9.31
Hokuriku	297023	19398	290974	0.980	25216	11.54
Kanto	821676	117161	420684	0.512	50405	8.35
Tokai	405360	41787	165016	0.407	29274	5.64
Kinki	375450	43505	181825	0.484	27280	6.67
Chugoku	387643	64483	203420	0.525	31770	6.40
Shikoku	229458	48653	94137	0.410	18800	5.01
Kyushu	615252	154776	319391	0.570	44374	7.20
Total	3834732	591551	2542283	0.663	372545	6.82

We get a differentiated picture of nine Japanese regions. We recognise a large difference in average size between Northern and Southern and Western Japanese Regions. Hokkaido the northern island has four times the average Japanese farm size. Tohoku and Hokuriku have 1.5 times the average Japanese farm size. All other regions have an average farm size of around half a hectare. Most of the farms we find in

Kanto area, the flat region of Tokyo area, with more than 0.8 million farms. Next come Kyushu region and Tohoku regions, both with more than 0.6 million farms. All other regions have less than 0.5 million farms. Hokkaido has the lowest number of rice farmers with less than 0.1 million. In Hokuriku region some 12% of the land area are paddy fields. Next comes Tohoku with 9% of the land area, Kanto with 8% and Kyushu with 7%. The mentioned areas have more rice fields than what is the Japanese average. All other regions have shares of under average.
For further consideration we include only those rice farms, that were actively selling on the market and exclude those that primarily produce for own consumption.

Table 7 Number of Selling Rice Farms According to Size and Region

	Special	*0.5ha <*	*0.5 - 1*	*1 - 1.5*	*1.5 - 2*	*2 - 2.5*	*2.5 to 3*	*3.0 to 4*	*4 to 5*	*> 5ha*	**Total**
Hokkaido	6		1862				5893		8330	24965	41056
Tohoku	663	66791	136051	95366	65500	43996	28443	30232	12287	11180	490509
Hokuriku	218	42349	81640	50206	29786	16557	9107	8292	2932	2568	243655
Kanto	2461	106024	187781	106696	59024	30449	14828	11937	3898	3421	526519
Tokai	1552	75957	105402	39213	14590	5458	2207	1497	468	705	247049
Kinki	1342	80382	104380	33400	10663	3628	1631	1255	518	542	237741
Chugoku	1031	72767	113494	45548	15729	5699	2304	1847	585	637	259641
Shikoku	1120	38495	63742	22505	7992	3215	1418	974	240	152	139853
Kyushu	2821	80642	139754	76082	42286	22614	11639	10038	3294	2411	391581
Japan	11214	563407	934106	469016	245570	131616	77470	66072	32552	46581	2577604

Source: Agricultural Census, 1990, only selling rice farms are included

In Hokkaido the farm size is collected according to a different scheme as farms are much larger than in the rest of Japan. All other regions have the same small scale farming classification. For simplicity we combined the two schemes in one table. Therefore more than half of the farms in largest farm class are situated in Hokkaido. The largest amount of small farms under half and one hectare can be found in Kanto region. In Hokkaido, where least rice farmers are, the number is more than three times less than in Shikoku, the second smallest region with rice farmers. Most farmers selling to the market are in Kanto and Tohoku regions.

Table 8 Differences in Scale of Rice Production in Major Japanese Regions (1990)

	Special	*0.5ha <*	*0.5 - 1*	*1 - 1.5*	*1.5 - 2*	*2 - 2.5*	*2.5 to 3*	*3.0 to 4*	*4 to 5*	*> 5ha*	**Total**
Hokkaido	1		820				7514		21207	124224	153766
Tohoku	101	18786	65351	75127	73362	64575	52033	69887	36227	49045	504494
Hokuriku	36	13223	46761	48506	40173	28656	19108	21308	9552	12583	239906
Kanto	292	25363	73150	67176	52964	35826	21727	21904	9331	11529	319262
Tokai	195	19645	43952	25413	12513	5349	2443	2048	904	3315	115777
Kinki	194	22886	49731	26057	11301	4715	2601	2509	1458	2790	124242
Chugoku	140	20296	54525	35806	16779	7428	3414	3215	1219	2058	144880
Shikoku	166	10226	27160	14348	6448	2964	1464	1160	400	366	64702
Kyushu	413	20931	57886	48481	35624	23142	13722	13767	5526	5384	224876
Total	1538	151356	419336	340914	249164	172655	124026	135798	85824	211294	1891905

Source: Agricultural Census, 1990, only selling rice farms are included

Most land for rice production is within the second smallest class with size 0.5 to 1 ha containing 22% of the rice producing area. Then there comes the third smallest class with 1 to 1.5 ha (18%) followed by the class from 1.5 to 2 ha (13%). Only on the forth place there comes the largest group, primarily because we included Hokkaido into this comparison (11%). Then there comes the group with size 2 to 2.5 ha, followed by the smallest group with farms under 0.5 ha (8%), followed by the groups 3 to 4 ha (7%), 2.5 to 3 ha (7%) and least area we find in the group of farm size 4 to 5 ha (5%).

3. LCA Methodology

3.1 General

We propose to introduce environmentally more benign production methods in rice production and evaluate the environmental performance with help of the LCA method. Degradation of environment and depletion of resources are most serious issues for humankind. The change of rice production methods in Japan contributed to this development. LCA appeared during the last 10 years in Japan and was applied for various products, in which one evaluates „from the cradle to the grave" impacts of products to the environment. A LCA approach for rice will include processes of the entire production cycle including preparation, sawing, cultivation, harvesting and post harvesting activities. Each activity related to rice production has to be related to a major process and the processes will be combined in the production cycle. Every activity is related to inputs and outputs until the product as final output of the production effort is gained. However, there are always some difficulties accompanying life cycle assessments on how to retrace repercussions in production systems and how to allocate inputs and outputs among multiple products.

3.2 LCA in agriculture

In Japan, agricultural products did not yet find too much consideration in LCA approaches, but it can be expected that this field is going to develop fast. In highly developed countries, most agricultural products can be regarded as industrial products as well. With the difference that in addition to human processes, natural processes have to be further considered. Instead of an industrial plant, steered by human decisions, one uses biological processes of nature to finalise a product. The inputs to rice production like agricultural machines, fertilisers and pesticides are industrial products.

The ideal of agricultural production during the last decades was to come ever closer to industrial production methods with a maximum of control and a minimum of surprise factors from nature. While the conditions of an industrial plant can be almost completely controlled, the production field in agriculture can only be controlled to a certain extend. In the case of Japanese rice production, water levels and soil consistency are usually controlled by field operators, but climate can not be controlled, unless rice is breaded in a glasshouse. Recent methods of tissue culture even show, that agricultural products can be generated in artificial environments that are closest to industrial production methods.

There are also principal differences to industry. Unlike in major industries, agricultural producers were not forced to the same extend to control their emissions to the environment. The farmer produces agricultural products outside urban areas. Different pollution loads, impairing soil-, water- and air quality can not accumulate in the same way like they doe in cities. Critical pollution doses of immediate health impacts are less likely in rural areas than in densely populated areas. The polluters and the victims are identical in the rural population and thereby confrontations as experienced between interest groups from cities are unlikely.

There are many more producers of agricultural products than of industrial products. The total amount of pollution caused by a single farmer is perhaps small in comparison to an industrial unit. The pollution is dispersed over a wide area and not concentrated. One can compare this situation to the effects of the high stack policy that was common in industry a few decades ago. There the pollution was dispersed over large areas without solving the problem at source. Forest die back and other large scale environment threats with possible consequence for the urban population led to regulations. In the case of rice production, usually near by the sea, the local soil and water system is effected. The extend of pollution ends up in the sea nearby coastal areas. Drinking water widely originates from the mountains and thereby major conflicts with the urban population was avoided. This situation was probably responsible, that the pressure to regulate environmental pollution in agriculture was considerably less than in industry. Another obstacle to regulate pollution originating from agriculture is the number of producers. It is more difficult to regulate the millions of farm units as compared to thousands of industries.

This situation can be changed by developing an appropriate framework with the help of LCA. We chose rice, the most important agricultural commodity for this purpose as rice covers about half of the agricultural production of Japan. We prepare a conceptual framework and mathematical framework to assess the problem.

3.3 Conceptual Approach of LCA in Rice Production

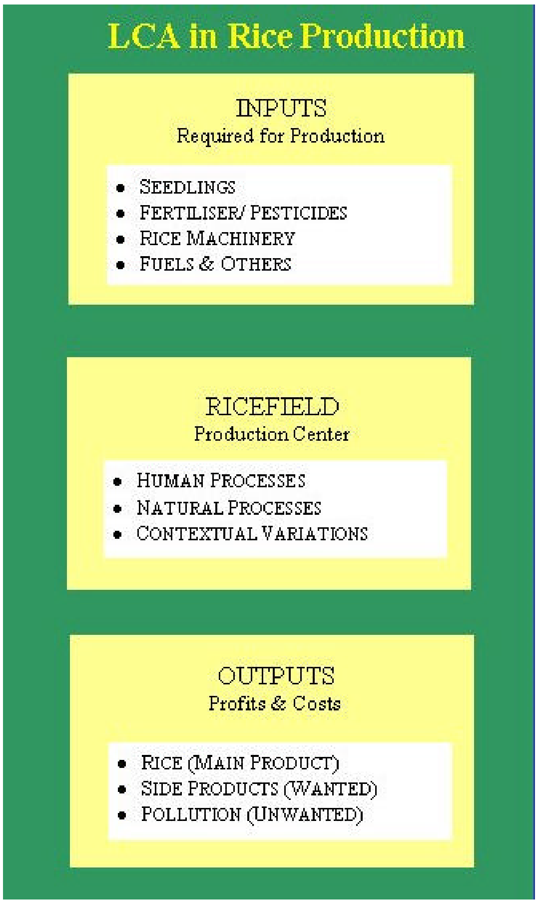

Figure 14 Scheme of LCA in Rice Production

In fig. 14 direct inputs and outputs to rice production, both related to a production centre, the rice field, are considered. We find main inputs like fertilisers, pesticides, machinery, fuels and other energy and get the output rice. In addition to rice we may get other wanted products than rice as well (e.g. a service of improving the local climate during summer time or a picturesque scenery) . But rice production is connected with pollution as well.

Table 9 Major Processes, Inputs, Outputs in Rice Production

Rice Production	*Inputs (human induced processes)*	*Production Centre (natural processes)*	*Outputs*
Tillage	Machines, materials	Rice field	Pollution (Emissions)
Growing	Machines, materials	Rice field	Pollution (Emissions)
Harvest	Machines, materials	Rice field	Product, Bye product
Total	Machines, materials	Rice field	Product, Bye product, Pollution

3.3.1 Inputs

We can differ between two kinds of inputs, those one can use during several years, e.g. agricultural machines and those materials which are consumed immediately, e.g. pesticides and fertiliser.

With an LCA approach we analyse in the first step the materials directly connected with rice production. This may directly allow to consider a reduction of inputs, which is not necessarily output related. An example would be if I can not increase my yield with additional fertiliser input or even decrease it. Or I can use agricultural machinery longer, before substituting it with new machinery. In such a case I can reduce inputs without an adverse effect on my output. The amount of pollution related to one unit of rice, will decrease.

At a certain limit, this simple reduction of inputs will no longer be possible. The next step will be a deeper analysis of the machines and materials. In such an analysis we can follow track of machines and materials. I will make a separate table of inputs and outputs from each machine required for rice production and divide it by the years possible to use it. Or take fertilisers or pesticides. But the production centre will shift to other places, where machines and fertilisers are produced, in many cases outside Japan.

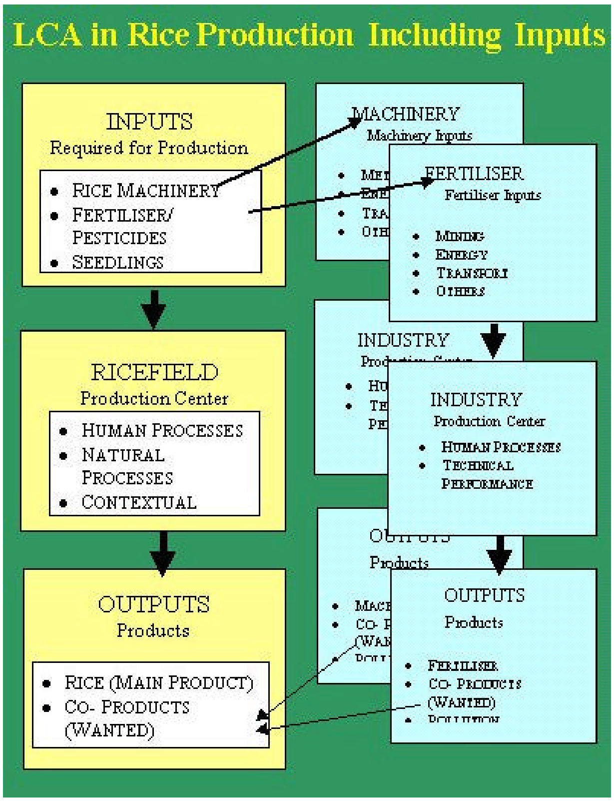

Figure 15 Analysis of Input Chain in Rice Production

As a consequence I will face the problem to locate the pollution problem, because for many inputs I doe not know where the production centre is, unless I consider global pollutants like greenhouse gases. In all other cases I am not able to locate the pollution related to inputs. This makes it further a difficult task to account for the total pollution related to LCA.

3.3.2 Production Centre

In the case of rice, an agricultural product, a field is the production centre. After we give our basic inputs on the field, we have natural processes converting our inputs to the product and other outputs. In the case of paddy, which covers more than 95% of rice production, these processes contain anaerobic reaction which leads to the generation of CH_4 and N_2O, greenhouse gases that contribute to global warming. In comparison to non agricultural, industrial products, the areas required for rice production are huge.

3.3.3 Outputs

The expected output is the main product, here rice, and bye products, like straw for tatami mats or other traditional Japanese products. Another output, along the rice growing cycle is the services provided by rice cultivation. The beauty of the traditional landscape or the cooling effect of neighbouring settlements and the protection against floods and torrents are just some of the services provided by rice growing.
We can distinguish between local, regional and global environmental pollution going out from the production centre which is in our case the rice field. Soil contamination is a local problem, water pollution is a local or smaller region problem and air pollution will be a regional or global problem, but in the case of agricultural production no local problem.

In the case of inputs, where SO_2 or NO_x are produced, we will have a regional pollution problem, if the pollution is produced in the same region, but we can not add the pollution resulting from far region imports. In this case we can add fuels resulting from the transportation.
All greenhouse gases, regardless where in the world the production centre is, can be added to the final accounting of pollution. Therefore the assessment for global pollutants is considered to be less complicated than other pollutants impairing the regional and local scale.

3.4 Mathematical Framework to LCA in Rice Production

Bottom-up method is most commonly used in developing life cycle inventories of investigated systems. In this method, inputs and outputs are listed up in a table of each estimated process, taking the relationships between the processes into consideration. Hence it has difficulties in allocating inputs and outputs among multiple products as well as retracing repercussions between the systems. In particular, we have to establish the method of proper allocation in the systems including multiple production or recycling of products. The amount of samples required to get the complete picture has to be high and at current we doe not have yet sufficient data for a bottom up approach. We assume however that within a more recent future we can undertake this effort. In the bottom-up method, inputs and outputs are usually allocated to each product in proportion to the weight or the mole number of them. These are called weight-based or mole-based allocation.

Certain inputs, for example a tractor, are not only used for rice production, but even for other agricultural products. The pollution share should therefore be divided between several products. In practical terms this might be a difficult attempt. This paper deals with a novel mathematical model of life cycle assessment called Process-relational Model. Utilising this model, we can dissolve the difficulties of LCA in retracing complicated repercussions and in allocating resource requirements and environmental emissions. The model consists of input and output matrix, including every process or activity in investigated systems. Thus it is similar to the Input-output analyses in economics, but different in including emissions and in taking recycle of wastes into consideration. Calculation of inverse matrix enables us to estimate direct and indirect resource requirements and emissions attributed to each activity in the systems.

Life cycle inventories allocated to each product should be consistent with those of overall systems. For instance, if there are tractors A and B, of which CO_2 emission allocated to tractor A is higher than that of B, and if all farmers select tractor B, CO_2 emissions from overall systems should decrease. However, weight-based allocation doe not generally insure the above mentioned consistency. We developed a novel mathematical formation called Process-relational Model, which can insure the consistency between each product and the overall system (Yoshioka et al., 1996).

Next we describe the mathematical framework of the process-relational model. Fig. 14 depicts a single process which needs to be put into a mathematical formation. We can deal with an element in fig. 14 either as a process or as a plant according to the boundary and purpose of evaluation and it will lead us further to fig. 15.

Fig. 14 indicates that all necessary inputs for activity $x_{j\,(=rice)}$ are expressed in equation (1).

$$a_j = \begin{pmatrix} a_{1j} \\ \vdots \\ a_{ij} \\ \vdots \\ a_{nj} \end{pmatrix} \cdot x_j \qquad (1)$$

Then all necessary inputs for all process's activities are expressed in equation (2).

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

On the other hand, products, by products and emissions are expressed as follows. Here we should note that this mathematical formation is different from input-output analyses 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. We have to modify the principle so as to make life cycle assessments including recycling or multiple production. For this purpose, we define the vector x 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 processes x. Thus we can include multiple outputs or emissions such as CO_2, NO_X, SO_X and heavy metals in equation (3).

$$y = Ex = \sum_{j=1}^{n} e_j x_j = \begin{pmatrix} e_{11} & \cdots & e_{1j} & \cdots & e_{1n} \\ e_{21} & \vdots & e_{2j} & \vdots & e_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ e_{n1} & \cdots & e_{nj} & \cdots & e_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_j \\ \vdots \\ x_n \end{pmatrix} \tag{3}$$

The following condition is obtained from equations (2) and (3), assuming f as a vector of final demand.

$$\begin{aligned} Ex &\geq Ax + f \\ (E - A)x &\geq f \end{aligned} \tag{4}$$

In order to determine x, we need criterion function for optimisation or simulation such as rojit function, on which actual systems depend. If actual systems are determined to minimise the total cost of overall systems, x is obtained by minimising the criterion function, cx. Equation (5) expresses the solution x, where the matrix B represents optimal basis of the minimisation problem.

$$\begin{aligned} x &= B^{-1} f \\ x_j &= B^{-1}{}_{j1} f_1 + B^{-1}{}_{j2} f_2 + \cdots + B^{-1}{}_{ji} f_i + \cdots + B^{-1}{}_{jn} f_n \end{aligned} \tag{5}$$

$$\frac{\partial x_j}{\partial f_i} = B^{-1}{}_{ji} \tag{6}$$

From equation (6) and (3), we can estimate outputs of Section K per unit of Demand I as shown in equation (7).

$$\frac{\partial y_k}{\partial f_i} = \sum_{j=1}^{n} \left(E_{kj} \times B^{-1}{}_{ji} \right) \tag{7}$$

Thus we can allocate resource or emissions to each product, even if a system include recycling or multiple production. This allocation principle is called BI allocation by Yoshioka et al. (1996).

Then we can estimate the improvement of an overall system as $EB_0^{-1}b_1$ when a new process b_1 is introduced in the system.

$$\begin{aligned} \Delta x &= -B_0^{-1}b_1 \\ \Delta y &= -EB_0^{-1}b_1 \end{aligned} \tag{8}$$

3.5 Sustainability of Resources and Emissions

We derive the necessary conditions for sustainable limitations on renewable resources, non-renewable resources and environmental emissions. The definition of sustainable consumption is obtained by investigating whether or not resource depletion and environmental crises can be avoided if the present rates of life-cycle efficiency and energy demands are continued (Matsuhashi et. al., 1996).

As far as non-renewable resources are concerned, the sustainability condition is derived as follows. Suppose that grade of a resource is expressed in the function of *f(R,P)*=R/P, then the following equation is obtained by differentiating the function *f(R,P)*.

$$\begin{aligned} \frac{\partial f}{\partial t} &= \lim_{\Delta t \to 0} \left[\frac{1}{\Delta t} \left[\frac{R_0 \exp(r\Delta t) - \dfrac{D_0\{1 - C_0 \exp(c\Delta t)\}\exp(b\Delta t)}{m_0 \exp(a\Delta t)\exp(s\Delta t)} \cdot \Delta t}{\dfrac{D_0\{1 - C_0 \exp(c\Delta t)\}\exp(b\Delta t)}{m_0 \exp(a\Delta t)\exp(s\Delta t)}} - \frac{R_0}{D_0(1-C_0) / m_0} \right] \right] \\ &= \lim_{\Delta t \to 0} \left[\frac{1}{\Delta t} \left[\frac{m_0 R_0}{D_0} \times \frac{\exp\{(a+r+s-b)\Delta t\}}{\{1 - C_0 \exp(c\Delta t)\}} - \Delta t - \frac{m_0 R_0}{D_0(1-C_0)} \right] \right] \\ &= \frac{m_0 R_0}{D_0} \left\{ \frac{a+r+s-b}{1-C_0} + \frac{C_0 c}{(1-C_0)^2} \right\} - 1 \end{aligned}$$

(9)

$$\frac{\partial f}{\partial t} \geq 0 \tag{10}$$

Accordingly equation (11) is obtained.

$$a + r + s - b + \frac{C_0 c}{\left(1 - C_0\right)} \geq \frac{D_0}{m_0 R_0} \left(1 - C_0\right) = \frac{P_0}{R_0} \tag{11}$$

R_0 = Reserves of the resources at initial time period.
R = Rate of increase of R_0 by improvement of geophysical prospecting and mining.
S = Rate of substitution by other resources.
$_0$ = Life cycle efficiencies of utilising the resources at initial time period.
a = Rate of increase of $_0$.
C_0 = Rate of recycle of the resources at initial time period. Although recycle is physically impossible in energy resources, it corresponds to the rate of cascading.
c = Rate of increase of C_0.
P_0 =Production of the resources at initial time period.
D_0 = Demand of the resources at initial time period.
b = Rate of increase of D_0.

Condition (11) indicates that depletion of a non-renewable resource can be avoided if the left-hand side including the factors of technological improvement is larger than the reciprocal number of R_0/P_0. Therefore we define this as a sustainability condition of a non-renewable resource.
Renewable resources can also be dealt with as follows. Stock type renewable resources are evaluated such as bio mass resources, since flow-type renewable energy harvested by photo voltaic or wind turbine systems doe not deplete. As conclusion, sustainability condition is the same as that of non-renewable resources except that r in Equation (11) corresponds to a rate of regeneration of a renewable resource.
Next we investigate environmental emissions such as anthropogenous CO_2 emissions. If we regard environmental emissions as negative resources, we are able to apply the same kind of condition as non-renewable resources. In evaluating CO_2 emissions, sustainability condition is the same as that of non-renewable resources except that C_0 in Equation (11) corresponds to the rate of absorption by the environment and that both r and c are zeros. In particular, we should note that C_0 is closely related with accumulation mechanism of CO_2 emissions.

Thus the sustainability condition on renewables, non-renewables and environmental emissions are shown to be similar. Accordingly we can deal with various resources and emissions in the integrated framework. The sustainability conditions enable us to evaluate how the technologies of efficiency improvement, innovative mining or heat cascading contribute to the sustainability.

(1) R/P of each resource is estimated based on proven reserves and production.
(2) Sustainability limitation of each resource is evaluated based on the above estimated R/P.
(3) The values in Eq. (11) are calculated as the average values between '70 and '90 for mineral resources and between '80 and '90 for energy resources.
(4) We can evaluate the distance between sustainable condition and actual situation of each resource as shown in Fig.1. This distance is defined as actual unsustainability.
(5) Reserves of those resources are supposed to increase as exploring and mining technologies are improved. Therefore we evaluated the value of r in Eq. (11) assuming that the proven reserve of each resource will approach the ultimate reserve in fifty years.
(6) We can investigate the potential risk of depletion of each resource, which is defined as potential unsustainability.
(7) As far as CO_2 is concerned, sustainability limitations and present situation is assessed based on airborne fraction, which is the rate of CO_2 accumulating in the atmosphere to maximum permissible accumulation in the atmosphere. Maximum permissible accumulation is assumed to be 560 ppm, twice of that in pre-industrial era.

A resource, of which the point is above the line, is judged to be sustainable. For example, copper is judged to be sustainable actually, since improvements in mining technologies increased the proven reserves. However, it is judged to be potentially unsustainable, since the ultimate reserve of copper is not so much. On the contrary, iron is judged to be potentially sustainable because of huge ultimate reserves, although it is actually unsustainable. Whereas oil and natural gas is judged to be actually sustainable, all energy resources except for coal is potentially unsustainable. Unsustainability of CO_2 is lower than that of natural gas, and is comparable with that of oil and higher than that of coal.

It is also indicated that energy resources and CO_2 emissions could threaten the sustainable development of humankind. Therefore we focus our analysis on greenhouse gases and CO_2 in the next section.

4. Possible Contribution of Rice Production to Reduce Greenhouse Gas Emissions in Japan

Here we investigate into the potential of reducing greenhouse gases in agriculture due to improvements in rice production. We want to recall that the Japanese government intended in the Kyoto Protocol to cut the total national greenhouse gas emissions by 6%. A large contribution should be due to measures related to agriculture (1997). Now we analyse the potential contribution of rice. The reduction potential is expressed in this section.

On the rice field we can differ between two kinds of processes, processes related to the activities of farmers and natural processes on the rice field. In the LCA assessment we have concentrated on processes in direct connection to farmers, because we suppose that they can be controlled to some extent. But we have further to consider the natural processes on the rice field. They are different according to the actual location, climate, topography and soil conditions, which are summarised in the regional picture of this analysis. In addition we may find other variations due to structural factors. For this reason another explanation is provided according to the size of farms.

In both cases we take the costs to produce 60 kg of rice as a basis for the input to the mathematical model described in the previous section. The differences in production costs can be found in table 10 and table 11. An important difference concerns the costs of different rice varieties. In 1990, the best rice varieties could be sold for 25,000, while the guaranteed rice price of the government was 16,500 Yen, about two thirds of the best price. In average the selling price was some 20% higher than the production price.

Table 10 Production Costs per **60kg of Rice According to Region (1990)**

	Japan	*Hokkaido*	*Tohoku*	*Hokuriku*	*Kanto*	*Tokai*	*Kinki*	*Chugoku*	*Shikoku*	*Kyusyu*
Nursery	340	178	278	519	337	456	418	333	470	290
Fertilizer	1028	777	1048	903	890	1208	1311	1423	1214	1008
Pesticide	865	722	763	854	697	977	885	1210	1153	1175
Light, heat and power	364	377	331	364	381	337	372	372	464	395
Other materials	255	271	207	208	327	352	323	343	200	206
Water utilization	745	684	849	954	746	483	611	354	846	648
Rental cost	1197	735	1313	1047	1052	1896	1449	1179	887	1256
Buildings and improving soils	538	637	407	661	459	607	731	661	1051	442
Agricultural machines	4914	3142	3869	5138	5079	5820	7229	6756	7902	5195
Labor costs	5972	3704	4730	5811	6952	8043	8025	8508	8374	5814
Sum	16218	11227	13795	16459	16920	20179	21354	21139	22561	16429
Byproducts	496	405	502	204	583	465	351	584	617	799

Source: Japanese Agricultural Census 1990

The production costs are twice as high in Shikoku as compared to Hokkaido. The main reason for this difference is the share of agricultural machines and labour costs, which are both 2.5 times in Shikoku than

Hokkaido, where we have also the largest rice farms. Therefore it is likely that selling prices were lower than production prices. The production costs were in this case partly subsidised by farm income outside the agricultural sector.

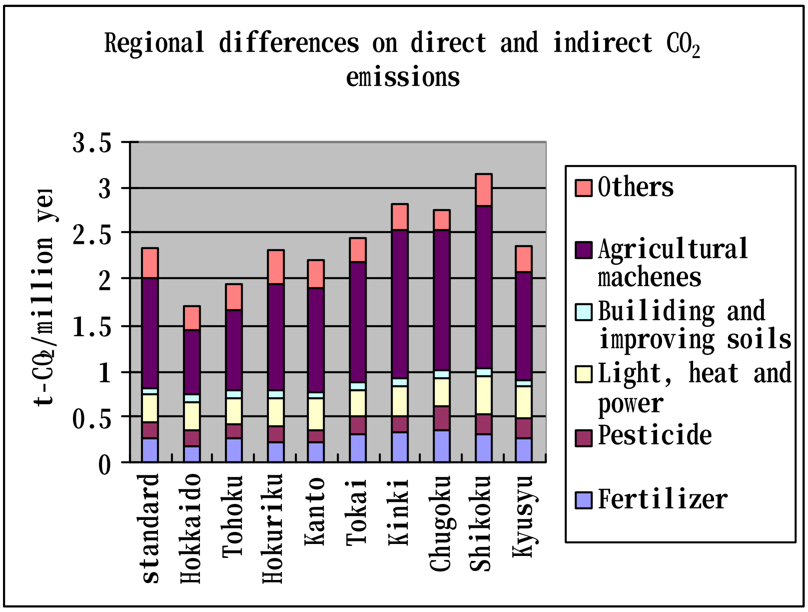

Figure 16 Regional Differences in CO_2 emissions of Japanese Rice Production (1990)

Taking rice value of 1 million yen we have in average 2.3 t CO_2 emissions. Shikoku is the region where we have with 3.3 t CO_2 emissions the highest value. In Hokkaido we have only about 1.8t CO_2 related to the same value of rice production. If we consider a producer price of Y400, we will be able to get 2.5 t of rice for this amount. If we take the farmers price for rice between Y275 and Y500, we get about 3.6 t of rice for this yen amount. Depending on the variety of rice we will get between 0.64 t to 0.92 t CO_2 related to the production of 1 t rice. Taking the total rice Japanese rice production from 1990 with 10.5 million tons, we can calculate the related CO_2 emissions with 8.2 million tons CO_2. The total CO_2 emissions (including other greenhouse gases) of Japan in 1990 were 920 million tons CO_2 or 7.7t per person. Rice contributed with 0.9% to the greenhouse gas production of Japan.

Table 11 Production Costs per **60kg of Rice According to Size**

	0.3ha	*0.5-1.0ha*	*1.5-2.0ha*	*2.5-3.0ha*	*5.0ha*
Nursery	673	419	244	200	193
Fertilizer	1243	1115	948	1031	846
Pesticide	1057	931	827	778	714
Light, heat and power	380	363	367	374	356
Other materials	330	288	212	157	264
Water utilization	766	730	688	806	703
Rental cost	2724	1620	836	675	504
Buildings and improving soils	873	596	444	381	552
Agricultural machines	6387	5733	4698	4110	3098
Labor costs	9752	7209	5082	4230	3363
Sum	24185	19004	14346	12742	10593
Byproducts	741	584	364	452	339

Source: Japanese Agricultural Census 1990

The regional differences is supported by the picture of the structural differences. Very small farms produce most expensive. The costs of machines is double and the cost of labour is three times as much at small farms.

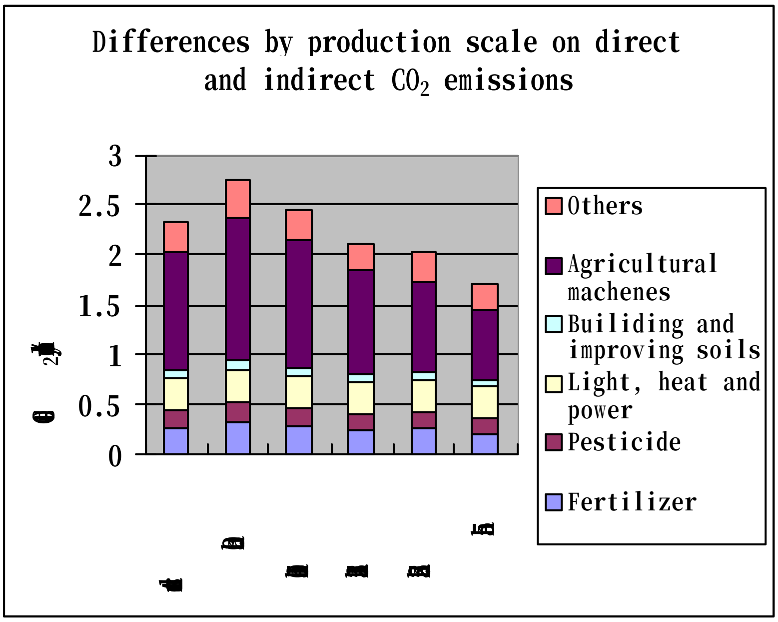

Figure 17 Regional Differences of CO_2 Emissions in Japanese Rice Production (1991)

We get large differences according to size, small scale production causes more pollution, but differences between small size and large size are less than differences of regions. There have to be more factors that explain the different costs and emission rates than the farm size. We propose to analyse high and low cost rice varieties and their regional distribution as a possible candidate to explain the emissions. Natural conditions may also have an impact.

In total rice production just accounts for about 0.9 % of the Japanese greenhouse gas emissions and the reduction potential will be considerably less than the total CO_2 emissions. The average Japanese rice consumption of 75 kg accounts for about 0.06t of the 7.7t CO_2 emissions.

If we consider current trends in rice production we can assume a reduction of greenhouse gases. A flat reduction of 1990 levels by 20% to 30% of per capita consumption (75kg) until 2010 (less than 55kg), is not impossible if we interpolate the trend observed during 1960 (118kg) to 1995 (68kg) will reduce between 0.1% and 0.2% of total greenhouse gas emissions in Japan. It is further likely that the smaller farms will abandon first and that the ecological efficiency in rice production related to the produced value will improve for structural reasons. According to first calculations, the potential of structural change may be another 0.1% of Japanese greenhouse gas emissions that could be avoided.

If we assume savings of inputs related to LCA can be one quarter as compared to the inputs in 1990, 0.1% to 0.2% of greenhouse gas savings is likely. Technological improvements in the production of inputs can total up to another 0.1% reduction. But, if we assume a continuation of total supply levels at 10 million tons and a stable number of farms, LCA efficiencies are expected to be more efficiently reduced at small farms. However, at current we consider this as an opinion. It will become the objective of our future work to assess the potential of this reduction. According to our first set of calculations, we belief that rice production will only account for half of the greenhouse gas emissions in 2010 relative to 1990 levels. Thereby some 8% of the job to be completed by Japan according to COP3 from Kyoto, will be done.

Even though the continuation of observed trends in rice production will have an important influence on the reduction of greenhouse gases, we consider the introduction of control measures resulting from LCA analysis as more important to reduce greenhouse gases. LCA can thereby become a powerful tool for a more sustainable Japanese agriculture.

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