Assessment of Rice Cultivation with Ecological Scarcity Japan

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Abstract

The ecological scarcity method Japan was developed through the adaptation of the most recent Swiss eco-factor 2006 method. It includes elementary flows and environmental impacts such as nitrate emissions to ground water, pesticides, and land use, in addition to climate change, ozone depletion, and so on.

The life cycle inventories of three different rice cultivation types in Japan are introduced. The life cycle inventories include the field cultivation processes, production of agricultural machines and materials used and refer to 1 kg of brown rice. The impact assessment is carried out with the ecological scarcity Japan method. Phosphate and nitrogen emissions to surface water are important pollutants. The use of natural resources, especially phosphorous extraction, is another crucial issue in the assessment.

It is concluded that the environmentally friendly cultivation can contribute to a reduction of the environmental load of Japanese paddy rice fields.

Keywords: rice cultivation, JALCA database, life cycle inventory, ecological scarcity Japan, life cycle impact assessment

1. Introduction

The Swiss ecological scarcity method is based on the distance to target principle. A critical flow is deduced for every substance where legislative guidelines or political goals exist. The current flow corresponds to the actual situation. The calculation of the eco-factor is determined by setting the current flow into relation with the critical flow.

Simplicity and transparency of the eco-factor calculation on one hand, and direct derivation from political targets on the other are this method's strength.

The use of political targets is the main difference to damage oriented approaches such as the Lime method or the eco-indicator 99. As a consequence, eco-factors can only be determined for substances with an applicable political target. Distance to target methods are criticized [1] because of the possibility to subjectively choose the target the critical flow should be based on in case more than one target exists. This is true for some impacts like for instance climate change but not for others such as e.g. eutrophication because the ecological scarcity method allows for regionalization. It was one of the first methods that provided regionalised eco-factors for water use [2].

There is a main advantage for companies to use the ecological scarcity method. It measures the ecological performance of a company (or its products) with reference to the political agenda of the country or region. In the case of a company this information can be more valuable and relevant than a damage oriented assessment. Furthermore the concept can be used to establish an ecological scarcity method valid for other nations or political entities. Several nations, for example Japan (JEPIX, [3]), have adopted the methodology in the past and are calculating own eco-factors based on their national environmental situation and legislation.

The ecological scarcity method Japan [4] is being developed through the adaptation of the most recent Swiss eco-factor 2006 method. Its purpose is to assess biofuel production and biomass utilization in Japan and thus it includes elementary flows and environmental impacts such as nitrate emissions to ground water, pesticides, land use, and fresh water, in addition to climate change, ozone depletion, and so on, although the method is in general applicable to life cycle impact assessment of Japanese products and services.

2. Methods: the Ecological Scarcity Formula

2.1 The formula representation

The formula representation that was used in the former two editions of the Swiss ecological scarcity method and the JEPIX method [3, 5, 6] is slightly changed (see formula (1)).

$$EF = 1EP \cdot \underbrace{K}_{\substack{\text{Characterisation}\\ \text{(optional)}}} \cdot \underbrace{\frac{1}{F_n}}_{\text{Normalisation}} \cdot \underbrace{\left(\frac{F_a}{F_k}\right)^2}_{\text{Weighting}} \cdot \underbrace{c}_{\substack{\text{Constant}\\ \text{(1e12 EP/a)}}} \qquad (1)$$

EP:	eco-points (the unit)	F_a:	actual flow
K:	characterisation factor	F_k:	critical flow
F_n:	normalisation flow	*c:*	constant (10^{12})

It allows for a more powerful interpretation. However, from a mathematical point of view the new representation (1) is only a conversion, leading to identical eco-factors as the previous one.

2.2 Characterisation, normalisation and weighting

The characterisation term improves the transparency of applying such factors. Characterisation was implicitly used in the previous versions (e.g. global warming potential) but is only now made explicit. The explicitly separated but optional characterisation term is in line with the impact assessment procedure according to the ISO standards. Normalisation is done with the current flow as suggested by the ISO standard 14044. The weighting factor is determined independently of the normalisation and is the square of the ratio between current annual emissions and the political targets in Japan.

The new formula allows to address regional or national differences combined with a Japanese perspective. Normalisation values represent the annual Japanese situation, whereas the actual and critical flows used in the "weighting" term are those of the region or nation of interest. This is particularly important with regard to water use, which shows high regional differences in scarcities (see for instance [2]).

3. Japanese Eco-Factors

3.1 Overview

Eco-factors are established for several pollutants and resources as well as waste flows. Compared to the version of 2010, additional substances are included such as heavy metal emissions to air, radioactive emissions to water and the resource use of non-renewable and renewable primary energy carriers. Furthermore, the method was tested and the feedback received was used to improve the foundation and/or the description of a few selected eco-factors. The ecological scarcity Japan method covers the following substances (substances added in 2011 are labelled with *):

Emissions to air:
- CO_2 and further greenhouse gases
- ozone depleting substances
- nitrogen oxide, particulate matter, NMVOC, *benzene, and sulfur dioxide
- ammonia
- dioxins
- *heavy metals (cadmium, lead, mercury, and zinc)

Emissions to surface water:
- phosphorous
- nitrogen
- organic matter (BOD/COD)
- *heavy metals (antimony, arsenic, cadmium, lead, manganese, mercury, and molybdenum)
- *radioactive emissions
- *adsorbable organic halogen compounds (AOX)
- *endocrine disruptors

Emissions to ground water:
- nitrate

Emissions to soil:
- heavy metals (cadmium, copper, lead, and zinc)
- *potassium
- plant protection products

Natural resources:
- *energy use (primary energy carriers, i.e. fossil, nuclear, and renewable)
- land use
- water use
- *gravel and sand
- *phosphorous

Wastes:
- *landfilled waste
- *hazardous waste
- *radioactive waste (high-level and low/medium-level)

In the following we shortly describe the eco-factors of a few selected substances.

3.1 Emissions to soil: potassium

Four different eco-factors are established with regard to potassium emissions to soil, namely for paddy rice fields, crop/vegetables fields, fruit plantations and a weighted average for unknown sites. The annual Japanese emissions of potassium to soil amount to 390’000 tons. The ideal potassium concentration in agricultural soils defined by the five most important producing prefectures served as a basis for the determination of the critical flow. The resulting eco-factors are 1’600 EP/kg, 5’100 EP/kg, 19’000 EP/kg, and 5’100 EP/kg for potassium emitted to paddy rice fields, to crop/vegetable fields, to fruit plantations and to unknown sites, respectively.

The method permits to calculate site-specific eco-factors depending on the project scope.

3.2 Emissions to soil: plant protection products

The determination of eco-factors for plant protection products was revised. The different plant protection products are still characterised with their effectiveness. The effectiveness is expressed by the reciprocal value of the standard dose, the latter being reported in kg active ingredient used per hectar. In contrast to the version of 2010, Japanese specific data were available, in particular for herbicides. The average standard dose of plant protection products applied in Japan is 13.4 kg/ha. In the fiscal year 2004 about 63'000 tons of plant protection products were used, which corresponds to a characterized flow of 773’000 tons PPP-eq. Japan aims at a reduction by 30 % compared to the situation in 1990/1992. This results in a critical flow of about 62'000 tons per year. The eco-factor of an average plant protection product is 1300 eco-points per kg PPP.

3.3 Natural resources: phosphorous extraction

The annually used amount of the natural resource phosphorous in Japan is about 565’000 tons. Phosphorous is mainly used in mineral fertilizers. By 2015 a cyclical use rate of 15% should be reached, which leads to a critical flow of 480’000 tons. The eco-factor is 2000 ecopoints per kg phoshorous.

4. Japanese Rice Cultivation

4.1 Overview

The purpose of applying a comparative LCA between organic, environmentally friendly, and conventional rice production systems is to clarify the possibility of organic rice cultivation. The organic rice produc systems analyzed in this study practices application of rice bran and machine weeding, which is commonly used in Japan.

4.2 Functional unit

The functional unit is 1 kg of brown rice after being dried and husked for post harvest management.

4.3 System boundaries and allocation

The system boundary includes rice production processes from tillage to husking (foreground processes) and manufacturing processes of seeds, fertilizers, compost, pesticides, fuels, machines, and so on (background processes).

Economic allocation was in principle applied as in the case of ecoinvent data 2.2.

4.3 Data quality considerations

Data on conventional and environmentally friendly rice production systems are based on commercial practices of H agricultural production corporation in Nagano Prefecture. Data on organic rice production systems are based on field experiments at the corporation conducted by the prefectural extention services. JALCA [7] was used for background processes including fertilizers and pesticides.

5. Results

5.1 Overview

The assessment of different rice cultivation types with the ecological scarcity method shows environmentally friendly cultivation is the most preferable followed by organic and conventional cultivation (Fig.1).

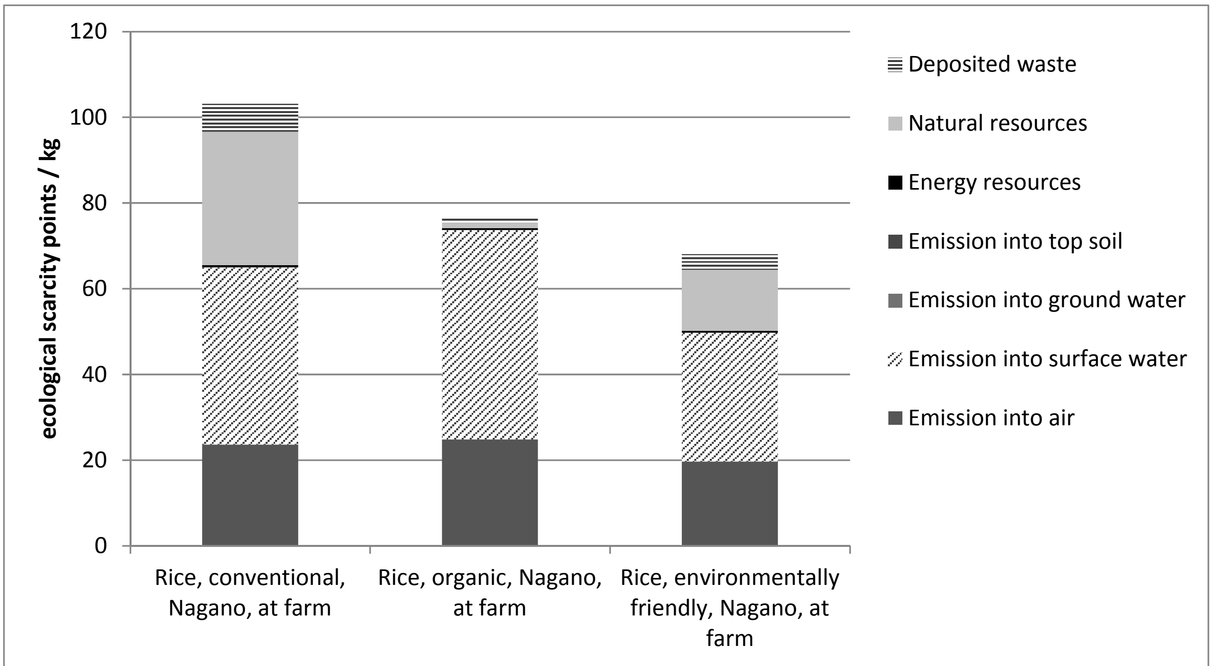

Fig.1: Assessment of conventional, organic and environmentally friendly rice cultivation in Nagano, Japan with the ecological scarcity Japan method.

In general, emissions into surface water are of high importance followed by the use of natural resources and emissions into air (Table 1). In conventional rice cultivation the use of phosphorous fertilizer contributes most to the overall environmental impacts. On one hand phosphorous fertilizer exhibit relatively high impacts due to the assessment of the non-renewable natural resource consumption of phosphorous to produce the fertilizer and on the other hand because phosphorous emissions to surface water during field application of fertilizers are considered. In organic rice cultivation no industrial fertilizer is used but phosphorous containing alternatives such as manure, compost, etc. which cause equivalent or even higher phosphorous emissions to surface water. In the environmentally friendly production industrial fertilizers are applied, which mainly explains the results concerning phosphorous emissions to surface water and use of natural resources. Nitrogen emissions to surface water are another important issue and are higher in organic as for conventional and environmentally friendly cultivation. Methane emissions into the atmosphere contribute to about 10% to the overall impacts in every type of cultivation investigated.

Table 1: Environmental impacts of different types of Japanese rice cultivation.

ecopoints/kg	conventional	organic	environmentally friendly
air	24	25	20
surface water	41	49	30
ground water	0.0023	0.00040	0.0013
soil	0.012	0.0096	0.010
energy resources	0.44	0.38	0.39
natural resources	31	1.3	14
deposited waste	6.6	1.0	3.6
total	**103**	**76**	**68**

6. Conclusions

The assessment of the life cycle inventories of three different rice cultivation types is performed using the Ecological Scarcity Japan. Environmental impact largely differ by cultivation method, in particular nutrient emissions into surface water. Improving cultivation technology has effects to decrease environmental impacts by 30 %.

The ecological scarcity method Japan allows for an aggregation of the emissions of pollutants and the consumption of resources into one single score. This characteristic of the method is one major subject of critique: The weighting factors show a high degree of arbitrariness. That is why it is recommended to involve national governments and their Ministry of Environment when developing a set of national eco-factors.

Recently published, the life cycle impact assessment method Ecological Scarcity Japan needs a phase of further testing in order to evaluate its usefulness in the environmental assessment of agricultural practices and products.

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