Comparison Analysis Between Rice and Cassava for Bioethanol Production in Japan Considering Land use Efficiency

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Abstract
The demand of rice in Japan is almost completely covered (99 %), however in the past years the total rice consumption had slightly decreased. In conjunction of an increment in the average age of famers as well as urban expansions, the arable land abandonment has also increased. In that sense, experts and researchers are considering alternatives to recover such lands. Consequently, studies on the possibility of producing bioethanol from rice in the abandoned arable lands in Japan have been presented. Nevertheless, rice production requires high water utilization furthermore, automated irrigation-systems are used for obtaining higher yields, indicating electricity and fuel consumption. On the contrary, crops as cassava root can be planted in poor soils with low to none electricity utilization. Utsunomiya city was selected as case study considering its food and fuel demand as well as the agricultural abandoned land available in Tochigi prefecture. The land use efficiency was analysed through a linear model. A range of feasible outcomes, as well as the net energy balance of two scenarios were studied. The design proposed is an on-farm bioethanol generation in order to reduce transportation costs; furthermore, self-sufficiency of electricity and heat through the use of CHP was included.

Keywords: Land use, bioethanol, on-farm, linear programing

Introduction

Considering the competition for land that has hitherto existed among food and biofuels it was modelled a self-sufficient farm, on energy and food, which is able to supply both without affecting one another. The concept of such farm was inspired by two concepts, multifunctional farms and integrated food-energy system (IFES) which are explained later in this work.

The land efficiency of farms was analysed as an alternative of the usual approach of cost minimization, aiming to an improvement of land use for later considering the policies necessary to do so. Land use limitation issues affect every country without exception; the intensification of urbanization as well as protected areas in conjunction with elderly farmers retiring have generated an increment of agricultural land abandoned. Therefore, the use of abandoned land is proposed to generate both food and fuel. The methodology presented allows decision makers to observe diverse optimal solutions according to their preferred goal: food or fuel.

The potential of current abandoned land for producing food and biofuel was analysed under two scenarios taken from optimal solutions. Scenario 1 considers fuel production as primal goal, while Scenario 2 includes food production as well.

The subject of study was Tochigi prefecture's abandoned land for supplying food and fuel demand of Utsunomiya city. Nonetheless with the goal of extrapolating to the southern part of Japan. A combination of cassava and rice was chosen to the extent of maintaining the self-sufficient ratio of rice (99 %) while including a high-energy crop.

Nomenclature and abbreviations

A	Area [ha]
CC_f	Calorific content of fuel [MJ/L]
E	Electricity [MJ]
Fl	Fuel [MJ]
f	Food [kg]
f_d	Food demand per capita [kg]
H	Heat [MJ]
i	Type of crop (ex: rice, cassava)
k	Percentage of population to supply fuel to [%]
m	Percentage of population to supply food to [%]
n	Population
R	Residue [kg]
Yc	Yield of crop [kg/ha]
Yf	Yield of fuel [L/kg]

Multifunctional farms

Multifunctional as the word indicates, represent several activities within one place or by one artefact. A multifunctional farm is then thought to produce more than food as conventionally presented. Nowadays by-products are as well obtained to generate for example bioenergy; furthermore beautiful sceneries from paddy fields are representing tourist destinations. T. Dobbs and J. Pretty (2004) indicate that "The idea that agriculture provides these other types of goods and services is not new, of course, and, in itself, is not controversial. The controversies surround how this concept is translated into policies" (Dobbs, 2004). The multifunctional farms addressed in this work describe the potential use of agricultural residues to produce electricity, heat and bio-fuel on-farm; furthermore evaluate energy outcomes and land efficiency considering policy change of *more fuel* or *more food*, in percentage of demand.

A farm where food and energy is produced within its boundaries has been described by the Food and Agriculture Organization (FAO) as Integrated food-energy systems (IFES). FAO proposes two types: "Type 1 combines the production of food and biomass for energy generation on the same land, through multiple-cropping systems, or systems mixing annual and perennial crop species and combined with livestock and/ or fish production (ecosystem approach). Type 2 seeks to maximize synergies between food crops, livestock, fish production and sources of renewable energy, using agro-industrial technology such as gasification or anaerobic digestion" (FAO, 2013). The previous concepts determine foundation and motivation of this work.

Abandoned land

The present work takes into consideration what is defined by the Ministry of Agriculture and Fishery of Japan (MAFF) as abandoned cultivated land. In 2010 it was reported a total of 396,000 ha abandoned (See Fig. 1), 1.8 times as for 1990 (MAFF, 2014). The increment observed has been driven by several factors, however the most critical is the retirement of elderly farmers; nowadays approximately 60 % of farmer population in Japan is over 65 years old.

Another reason of abandonment has been the decrease in rice and tea demand; however the self-sufficiency ratio of the former one increased from 97 % to 99 % because of higher yields achieved. In this way of thinking, some researchers have been considering other alternatives of utilizing such lands for energy production. “Utilization of such abandoned cultivated lands as well as marginal lands could bring opportunities for rural development. For that purpose, choices should be made carefully regarding locations and which feedstocks to cultivate. Also, the potential impacts of biofuel crop cultivation on existing ecological systems and possible indirect GHG emissions due to land use change should be considered” (Matsumoto et.al., 2009).

According to Matsumoto, N. et.al. (2009), the first collaborative project plan approved in December 2008 to produce ethanol was from rice, furthermore on unutilized rice fields, beside other previous projects organized by MAFF for larger scale. Nevertheless, current import is greater than production and is done exclusively from Brazil. Table 1 presents the fuel ethanol imports in Japan in the last nine years.

Table 1. Market penetration of ethanol in Japan

Market penetration	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fuel ethanol [kL]	30	90	200	15,000	27,811	52,146	56,067	79,114	91,700

Kanto and Tozan area were considered, more specifically Tochigi prefecture because it has the greater agricultural land abandoned as observed in Fig.1. Furthermore, it was applied a conservative land use factor of 70% as used in city planning when taking into account future generations and its development.

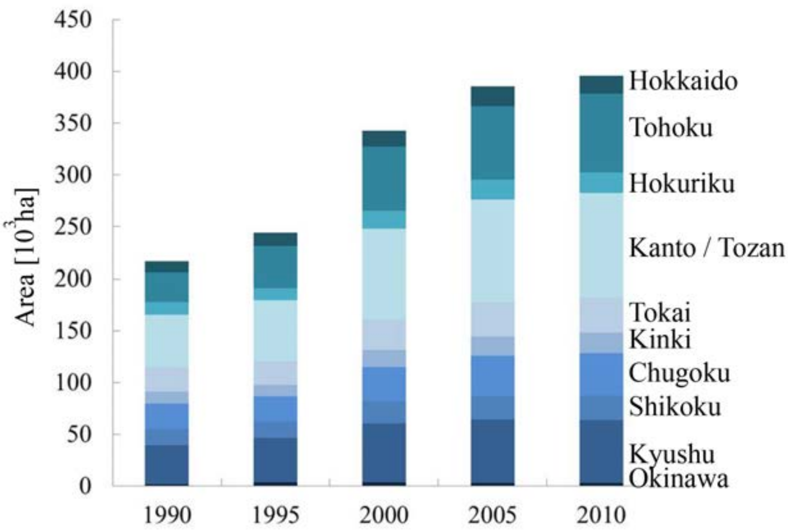


Figure 1. Agriculture abandoned area in Japan

Crops analysed

A difference among edible and non-edible fraction of the plant was considered to be able to distinguish the actual dilemma of food versus fuel, since it is the edible fraction which encounter such issue. Furthermore, the model developed in this research describes the use of edible fraction for food or fuel as main factor in the objective function; then non-edible fraction is treated as resource to generate either electricity and heat (CHP) or biofuel.

The use of human food as resource for ethanol production has created extensive debates, considering that there are about 827 million undernourished people in the world according to the FAO (2012). Nevertheless Japan does not face such issue directly, using a staple food as it is rice for such purpose it may create a risk; furthermore if considering factors as the great east earthquake that affected the country in 2011.

In this way of thinking, the utilization of cassava is proposed as an alternative, comparing the efficiency of using one or both for bioethanol production. It has been observed that rice uses great amount of water, it may not have high bioethanol yield as other crops like sugarcane or cassava as well as it could affect its market price. The use of Cassava instead, may not improve directly the food self-sufficiency ratio however will not reduce it since is not a staple food in Japan. Furthermore, there is an opportunity of using locally produced cassava chips as feed to increase livestock production as an alternative of importing corn as currently.
A brief description of the crops analysed is as follows; furthermore energy content and yield data used are in Table 2.

Rice
Is a cereal grain widely used as staple food in many countries, however is stronger in Asia where an area of 1.4×10^6 km^2 is harvested. In Japan, rice represents a staple food and nearly the only agricultural product that is exported. The self-sufficient ratio of rice in Japan reaches 99 % (MAFF).

Rice has grown interest as starchy resource for bio-ethanol production, mostly because of the concern about its bulky agricultural residue and possible uses as biomass. The edible part of the plant is the grain while the husk and straw are the residues as shown in Fig. 2. Furthermore, as observed in Table 2, residue is produced almost as grain. Rice is worldwide grown and there are many species, *Oryza sativa* is majorly found in Asia and *Oryza glaberrima* in Africa.

There are other many species and several researches intend to increase its yield for bio-fuel production. Nonetheless, the interest is usually on the residues because if it is left on the field causes erosion, therefore is a "free" resource. Furthermore, the global bioethanol potential from residues is estimated to be 205 GL (Kim, S. 2004).

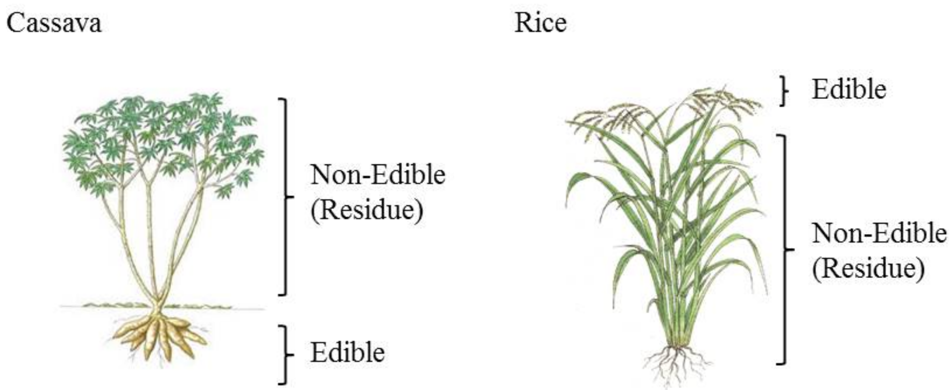


Figure 2. Edible and non-edible fractions of rice and cassava (Source: FAO)

Table 2. Energy content and yield of rice and cassava

Crop	**Edible/ Non-Edible fraction**	**LHV [MJ/kg]**	**Yield [kg/ha]**	**Ethanol Yield [L/kg]**
Cassava	Stem, rhizome	18.42	3,854	0.14
	Root	15.90	14,527	0.41
Rice	Husk, straw	14.27	5,126	0.28
	Grain	15.20	6,210	0.48

Cassava

Manihot esculenta Crantz by its scientific name is the third most important source of calories in the tropics after rice and maize (FAO). "Cassava is a woody perennial shrub, which grows from 1 m to 5 m in height. It is believed to have been cultivated, mainly for its starchy roots, for 9,000 years, making it one of agriculture's oldest crops" (Howeler, R. et.al. 2013). History suggests it was originated in South America and later during colonization times, it was extended to Africa and Asia, being the former one where is widely used as staple food. Currently Thailand is the major exporter of cassava followed by Vietnam.

Even though cassava has been established greatly in tropical regions, nowadays it can be found under lower temperatures as well, because it can grow in low quality soils or marginal lands. It is observed in Fig. 3 an extension to the north of the Tropic of Cancer, particularly in China, of cassava uses. In China the interest for biofuel production with cassava has increased notably. C. Janson et.al. (2009) say that "recently, cassava-derived bioethanol production has been increasing due to its economic benefits compared to other bioethanol-producing crops in the country". As well in United States, where there is no published nationwide production of cassava, a study in Alabama suggested that "with warmer maximum and minimum temperatures and a frost-free period of over 220 days was sufficient to produce significant root biomass" (Ziska, L. H. et.al., 2009). Therefore we considered cassava as an alternative to make use of abandoned and marginal lands in Japan in near future, without affecting food security.

The stem, leaf and rhizome are considered in this work as residues as observed in Fig.2. However, some regions in Africa consume the leaves in spite of it toxicity if is not treated well.

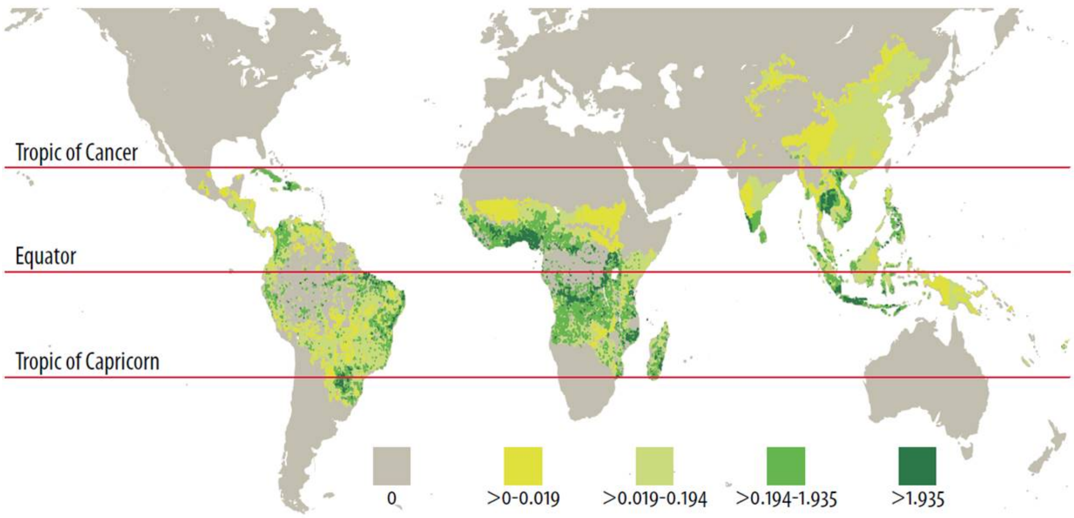


Figure 3. Cassava plantation worldwide [ha/km^2] (Howeler, R. et.al. 2013)

Background

The current research analyses the use of rice and cassava for ethanol and food production together and not exclusively as have been observed in several previous researches. Furthermore, it analysed the Net Energy Balance (NEB) considering *Labour* because it was noticed that it has been excluded. However, labour is a variable that must be taken into account because first it represents of about 30 % of agricultural cost and secondly because there are notably differences of its intensity among crops.
In this work NEB values and energy production of a design where cassava and rice are used were compared to a one-crop system; one case of only cassava and another one of only rice. In Table 3 a summary of variables considered and compared with previous researches is presented.

Case study

As said before Tochigi prefecture was selected, furthermore the city of Utsunomiya. The target population is about 511,739 inhabitants with fuel consumption per capita of 14,047 MJ and annual electricity consumption per capita of 7,848 kWh. Currently, Tochigi has 43 thousand hectares of agricultural land abandoned. The objective of this work is to analyse the potential of such land to supply fuel and food demand of Utsunomiya.

Table 3: Comparison of previous studies

		This research	K. Saga et. al.	Nguyen
Agriculture production	Rice	✓	✓	
	Cassava	✓		✓
Final product	Food	✓		
	Fuel	✓	✓	✓
	Electricity	✓	✓	
	Heat	✓	✓	✓
Indirect energy	Seeding	✓	✓	✓
	Fertilizer, Manure, Pesticides	✓	✓	✓
	Irrigation	✓	✓	✓
	Machinery, Vehicles	✓	✓	✓
	Labor	✓		
	Others	✓	✓	✓

Methodology

Figure 4 represents the schematic design of the farm proposed. As observed, edible fraction of crops is used for food and fuel, while its residues could be used for biofuel and cogeneration of electricity and heat. Electricity and biofuel are used in the agriculture process as direct energy inputs, while indirect inputs come from outside farms limits. Heat is used for biofuel production on-farm.

Typically in agriculture, the selection of crops is denoted by a minimization of cost or maximization of profit approach. However, the land variable is not directly studied. Therefore, a minimization of land used approach was analysed where the objective function considers land for food and for fuel (E.q. 1).

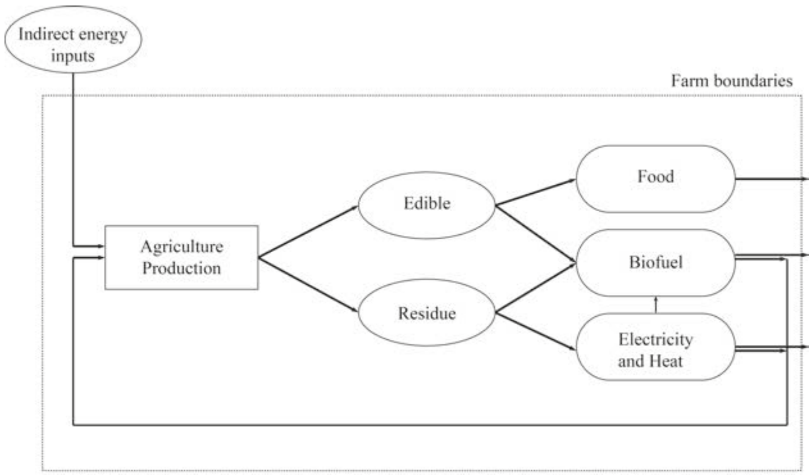


Figure 4: Conceptual system design

$$\min A_{total} = min\left(\sum_i A_{food_i} + \sum_i A_{fuel_i}\right) \quad (1)$$

where the area for food (A_{food_i}) can be expressed in terms of food produced (f_{out_i}) and crop yield (Y_c) (E.q. 2). Analogously the area for fuel (A_{fuel_i}) is based on fuel produced (Fl_{out_i}) and fuel yield (Y_f) (E.q. 3).

$$A_{food_i} = \frac{f_{out_i}}{Y_{c_i}} \quad (2)$$

$$A_{fuel_i} = \frac{Fl_{out_i}}{Y_{c_i} CC_{f_i} Y_{f_i}} \quad (3)$$

Residues (R) are planned to be used for electricity, heat and fuel generation (E.q.4). A fraction a is for biofuel and a fraction b is for cogeneration. Therefore $a+b=1$.

$$\mathrm{R}_{Total} = a\sum_i \left(R_{food_i} + R_{fuel_i}\right) + b\sum_i \left(R_{food_i} + R_{fuel_i}\right) \quad (4)$$

The constraints implemented are as follows:

1. Total electricity produced (*E_{out}*) has to be equal or greater than electricity needed on-farm (*E_{in}*) (see E.q. 5)

$$E_{out} \geq \sum_i E_{in_i} \tag{5}$$

2. Total heat production (*H_{out}*) has to be greater or equal than heat for biofuel production (*H_{in}*) (E.q.6).

$$H_{out} \geq \sum_i H_{in_i} \tag{6}$$

3. Food produced (*f_{out}*) has to supply food demand per capita (*f_d*) to a percentage m of the target population n. (E.q.7)

$$f_{out_i} \geq m.n.f_{d_i} \tag{7}$$

4. Fuel produced (*F_{out}*) has to supply on-farm fuel use (*Fl_{in}*) as well as a fuel demand per capita (*Fl_d*) to a percentage k of the target population n.

$$Fl_{out} \geq \sum_i Fl_{in_i} + k.\ n.Fl_d \tag{8}$$

An iteration of m and k is analysed with the objective of understanding the limitations and potential of the land available as well as optimal solutions. Such iteration is evaluated from zero to 100 % in intervals of 1 %.

After obtaining the feasible region, two "extreme" scenarios are analysed and compared:

- Scenario 1, *Only-fuel Scenario*: Describe a policy where producing fuel is the goal. In other words it could be seen as an energy secure scenario.
- Scenario 2, *Food&Fuel Scenario*: Is the maximum efficient use for land targeting both food and fuel.

From each Scenario the following can be obtained: the values of m and k for which it is are feasible, the optimal share of rice and cassava, and the net energy balance (NEB). Such balance is calculated by subtracting energy output from energy input.
The data used in the model are in Table 4 and Table 5.

Table 4. Data used in the model

Crop	**Rice**	**Cassava**
Food demand per capita [kg]	43.30	0.10
Crop yield [kg/ha]	5,110.00	14,527.20
Labour [h/ha]	24.00	952.86
Electricity [kWh/ha]	120.00	14.93
Fuel [MJ/ha]	3,118.00	3,528.57
Residue	**Straw**	**Stem and Rhizome**
Residue Yield [kg/ha]	4,218.82	3,854.07
Calorific content residue [MJ/kg]	14.27	18.42
Calorific content full crop [MJ/kg]	15.20	15.90
Bioethanol production		
Ethanol conversion rate residue [L/kg]	0.28	0.14
Ethanol conversion rate crop [L/kg]	0.48	0.41
Electricity input [kWh/L]	0.39	0.34
Heat input [MJ/L]	10.65	6.36
Calorific content output [MJ/L]	22.00	21.12

Source: Pimentel&Pimentel (2008), Nguyen T.(2008)

Results

In Fig. 3 the feasible region obtained from the model by iteration of *m* and *k* values can be appreciated. A gradient of colours was used to indicate the land needed to achieve different fuel and food production respect to demand. As well, Scenarios selected are detailed. From here it can be noticed that Scenario of Food and Fuel use land more efficiently because with nearly the same area it could produce 100 % of food demand and 42 % of fuel demand in contrast of Only-Fuel Scenario that reach 38 % of fuel.

Table 5. Data used for NEB

	Energy input [MJ/ha]	Rice	Cassava
Direct	Electricity	1,308.00	162.74
	Fuel	3,118.00	3,528.57
Indirect	Seeding/Sticks	558.64	1,126.00
	Fertilizer	7,896.25	3,591.00
	Manure	-	23,684.00
	Herbicide and insecticide	5,183.91	-
	Others	804.42	-
	Irrigation	2,129.01	-
	Agricultural service	5,337.28	-
	Facility	2,628.43	-
	Labour (h/ha)	3,432.00	21,216.00
	Vehicles	1,517.35	-
	Machinery (kg/ha)	11,975.92	391.00
	Production management	43.75	-

Source: MAFF (2010), Pimentel&Pimentel (2008)

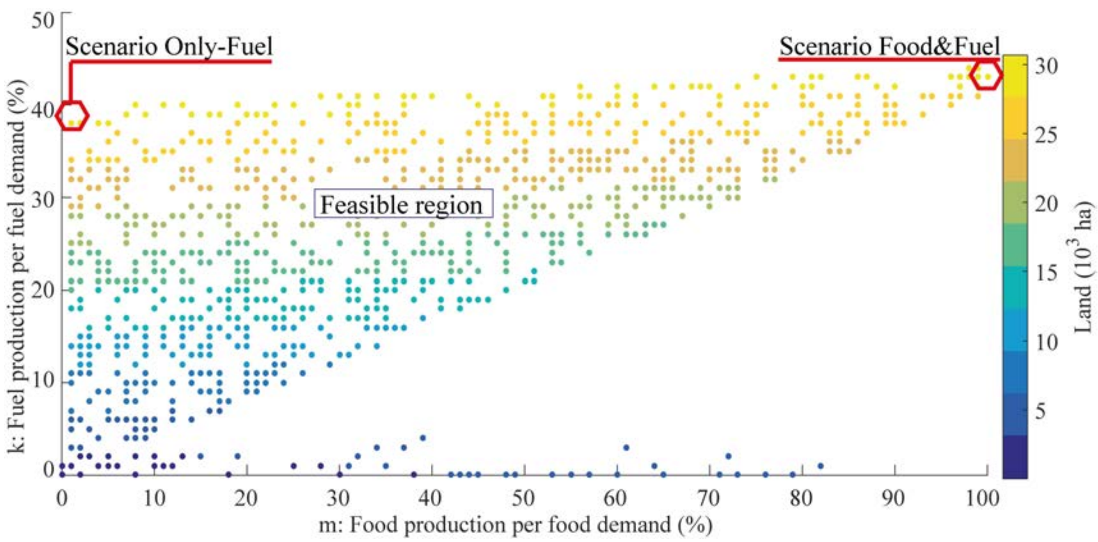


Figure 3: Feasible region obtained from iteration of *m* and *k* values from where two scenarios were chosen.

The optimal combination of crops for each scenario is shown in Fig. 4, from where it can be observed that for Scenario of Only-Fuel, cassava is preferred over rice. Furthermore, the combination of 41 % of the land for rice and 59 % for cassava in Food&Fuel Scenario allows slightly less land use than in the previous one.

When observing results heretofore it can be noticed that for cassava-rice configuration in our case study, it does not exist apparent *food versus fuel* dilemma, instead it indicates that the target population selected can be self-sufficient on rice and at least 41 % on fuel.

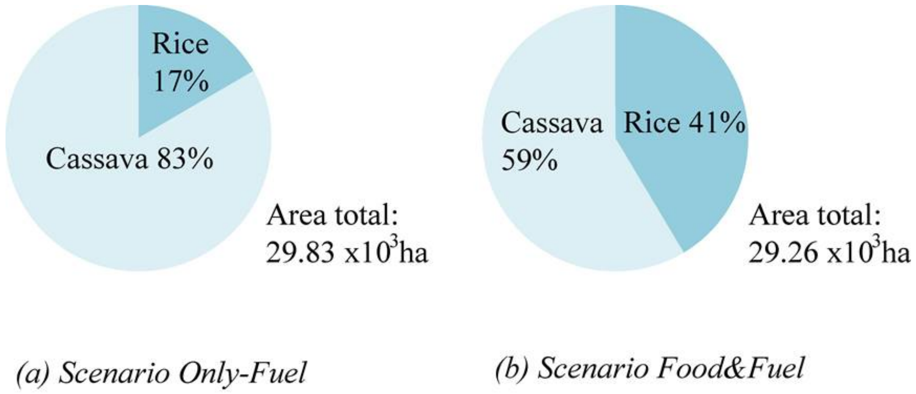


Figure 4: Land used by different crops in the two scenarios selected

As described in the methodology section NEB was analysed for the two scenarios described. In this study direct energy input are electricity, heat and biofuel, all produced on-farm. Electricity and fuel are used for irrigation and transportation as agricultural inputs, and electricity and heat are used for biofuel production. Indirect energy was indicated in previous section. Even though Food&Fuel Scenario revealed to have higher land efficiency based on the amount of food and fuel produced, it can be observed in Fig. 5 that its actual energy balance is lower than for Only-Fuel scenario. Nonetheless, both Scenarios 1 and 2 have positive balance of about 71.99 GJ/ha and 80.99 GJ/ha respectively. It is thought that the differences between them relies on that the energy output in food is not considered in Scenario 2.

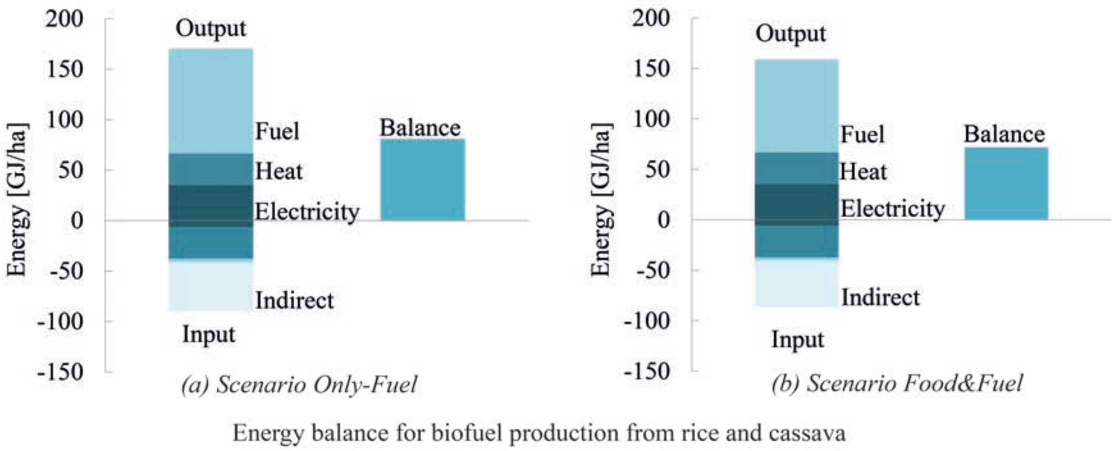


Figure 5: Energy balance for biofuel production from rice and cassava for the two scenarios selected

In Fig. 6 the energy flows are represented by Sankey diagrams for easier understanding of results. Both scenarios are compared with previous research of only-rice and only-cassava cases. It can be observed that the optimal share obtained in this research achieves higher ethanol production per hectare (approximately 10-13 GJ/ha higher), from which Scenario 2 provides the highest potential; moreover generates its own heat and electricity on-farm.

As well it can be noticed that residues are used for electricity and heat production however not for biofuel, despite of being proposed as alternative in the model. Another aspect observed is that heat generation matches own consumption, meanwhile a surplus of electricity can be obtained.

Discussion

Producing fuel does not imply a food security dilemma considering land use, however is the choice of crops what determines such issue. Due to the non-direct consumption of cassava as food it was obtained that in combination with rice the case study presented achieves food security and about 41 % of fuel demand. Nonetheless, cassava does have a market in Japan in the form of starch or already processed as tapioca balls due to the import of Thai food. Currently China and Japan are the biggest importers of cassava starch due to paper industry (80 % of total production). A further study of market price should be analysed; as well it could be considered the use of cassava chips for feeding purposes in comparison with the current use of corn, which is also an imported good.

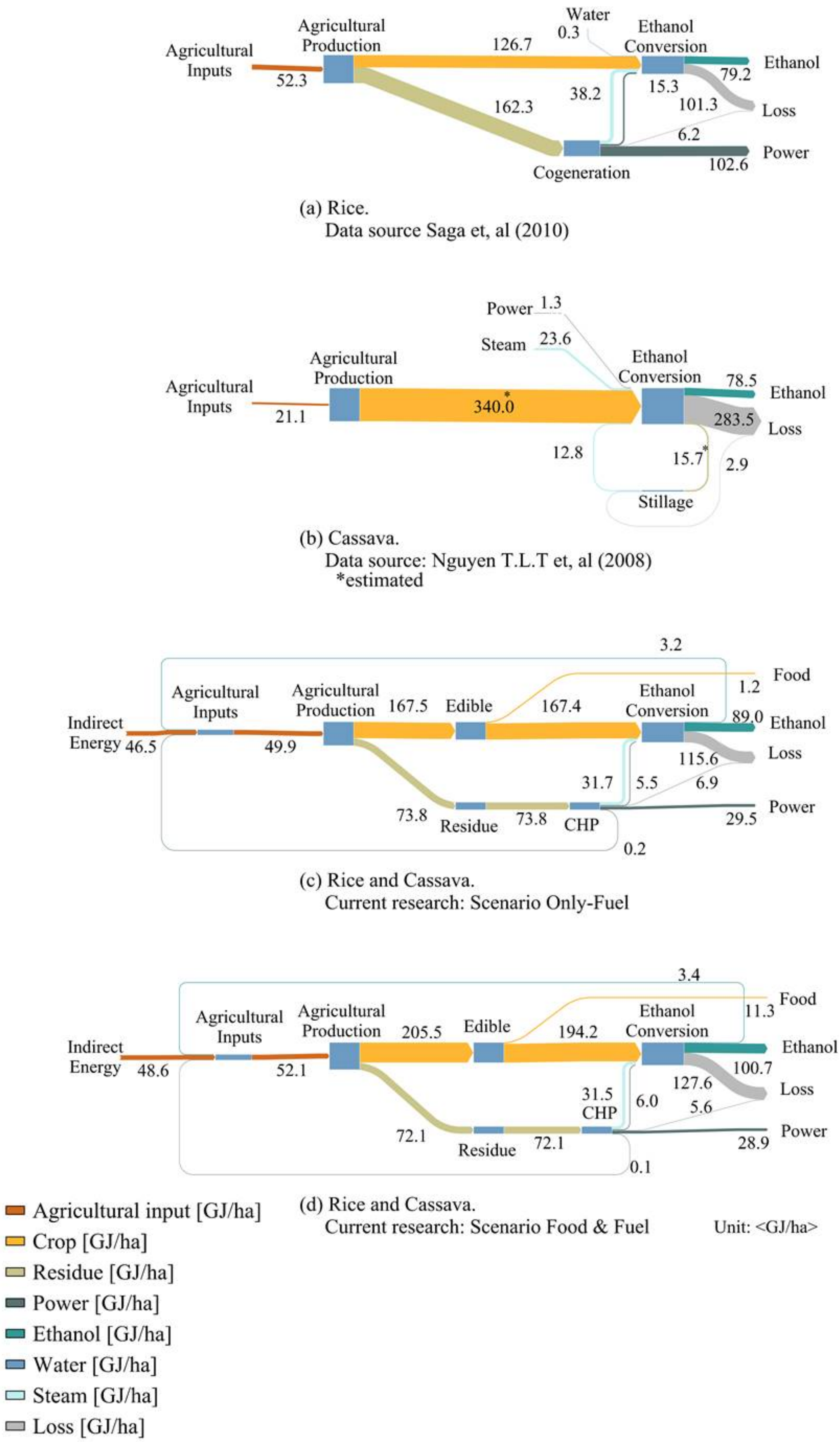
The NEB obtained for both scenarios is 80 GJ/ha and is approximately 40 GJ/ha lower than the best balance scenario presented by Saga et.al 2008. Nonetheless the indirect energy input from labour was included; which is intensive, especially for cassava. Despite lower balance, the bioethanol yield per hectare is higher.

If current design is applied from middle to southern area of Japan the bio-ethanol potential could reach up to 19 PJ, or 906,107 kL which is equivalent to 130 % of imported bio-ethanol in 2010.

Conclusion

One of the advantages of using the methodology described is that decision makers are not influenced by only one solution, instead can observe the big picture moving forward more efficient systems.

It was observed that providing about 40% of fuel demand of Utsunomiya City leaves land to supply from 1% to 100% of rice demand depending on the optimal share of crops or the objective of decision makers, either only fuel or food and fuel.



(a) Rice.
Data source Saga et, al (2010)

(b) Cassava.
Data source: Nguyen T.L.T et, al (2008)
*estimated

(c) Rice and Cassava.
Current research: Scenario Only-Fuel

(d) Rice and Cassava.
Current research: Scenario Food & Fuel

Figure 6: Energy flow of the two scenarios selected and previous researches

Producing both food and fuel at its maximum possible by land available, using Scenario 2, ensue higher ethanol production approximately 11.7 GJ/ha compared with only-fuel scenario. Moreover, food demand of rice for the case study is completely accomplished locally.

It is recommended a soil study for cassava plantations. However, it is known cassava grows in poor soils and marginal land; furthermore there are studies that indicate crop rotation as a mechanism to improve soil quality.

Results indicate that producing bio-ethanol not necessarily affects food production, instead could be done in conjunction if a proper choice of crops is done. Japan land is known for not being as productive as in other countries; however crops like cassava which does not collide with food security and can be planted in marginal land, provides a high opportunity for biofuel production, therefore increasing energy security.

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