PREFACE

This research manuscript on the estimation of the global potential food and biofuel production takes its present shape with the contribution of IVEM staffs. Especially, I want to express my gratitude to Dr. Sanderine Nonhebel for her dedication and support with valuable advice, material and comments in conducting this research from proposal development to the end of report writing. I also want to acknowledge Professor Dr. Ton Schoot Uiterkamp for his valuable advice and contribution. I want to extend my appreciation to Mr. Michiel Berger for his advice on the progress of my research to use my time efficiently and on other issues that helps me to be successful. I need to acknowledge also other stuff members for their contribution to equip me with the research knowledge and skill. Last but not least I want to thank Ms. Annemiek J Huizinga for her assistance in providing me with a printing card and reshaping the final manuscript.

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SUMMARY

The large scale biofuel production began in 1970s in USA and Brazil. Currently, USA is leading the global biofuel production by 40% from corn followed by Brazil (34%). Nevertheless, it is considered as one of the triggering and underlying factors for soaring crop prices [FAO, 2008; Rosegrant, 2008] that it competes with food consumption. Yet, it is also considered to be one of the future substitutions for fossil fuel and a source of income for developing countries. But, most of the studies on potential biofuel estimation are on total biomass rather than on energy crops which can be divided between food consumption and biofuel. In addition, some of the studies mainly focus on the global suitable agricultural lands without consideration of environmental integrity from deforestation. Thus, this may not indicate the competitive nature of food and biofuel. Therefore, this study gives insight in and consideration to the globally available agricultural lands starting from the present production system and yields. Subsequently, the future production potential, food demand and surplus agricultural land were estimated by means of a scenario analysis. The scenario analysis focused on the maximum potential production of food and biofuel. It was accomplished by expansion of present arable land (1.6 Gha) by 75% to pasture land, shifting of meat production system to monogastric animals and doubling of the present yield. All the production was converted to grain equivalent in order to include the different composition of human diets and comparable products. In order to calculate the amount of surplus agricultural land, the moderate consumption pattern with food security criteria production-demand ratio of 2 was used. The surplus agricultural land after satisfying the demand with a moderate diet was used for biofuel potential production calculation. Hence, 0.9 EJ of energy from bioethanol was estimated. This production was compared with the 2025 total global energy demand forecasted. It was concluded that potential 0.9 EJ contributes 0.14% of the total global energy or 0.5% of the global oil demand forecasted. But also some factors, like the fossil fuel input from crop production to fuel processing and subsequent environmental pollution were investigated from their life cycle analysis. Therefore, the substitutability of biofuel as a renewable source of energy for fossil fuel is not very promising by producing biofuels from surplus agricultural lands. A calculation was also conducted for first generation biofuel production from degraded lands, and found to be a promising source of income for poor developing countries and as a source of domestic energy supply.

CHAPTER 1

1.1 Introduction

The first large-scale schemes biofuel production began in the early 1970s in Brazil and in US. Currently, US constitute 40% of the world's biofuel production followed by Brazil (34%) and European Union 7%) (Peskett *et al*., 2007). Recently it has been given notable worldwide consideration as a fossil fuel alternative. It is also considered to be a good opportunity for developing countries with large surface areas of land to have the opportunity to produce and export in a competitive market (Peskett et *al.*, 2007; Cadenal and Cabezudo, 1998). Another study by UN (2007) indicates multi-benefit for people in sub-Saharan Africa. It claims that, people can use energy crops as a source of income. But also as a means of transition from traditional biomass fuel to improved modern stoves which can be operated by biofuel. This may subsequently result in reduced deforestation and improved health of women and children from reduced indoor air pollution.

Nevertheless, currently biofuel is considered as one of the triggering and underlying factors for soaring crop prices since it competes with food consumption (FAO, 2008; Rosegrant, 2008). FAO (2008) reported 37 countries around the world that need emergency food assistance for which biofuel production is claimed to be as one of the underlying factors. It is the fact that both food and biofuel production share the same resources in a competitive manner. Human needs food to eat that is produced from available agricultural lands with the increasing demand due to change in consumption pattern. On the other hand, the increasing demand in energy consumption, climatic change and the prospective of fossil fuel intensify the need for scientists to find a lasting option. Thus, biofuel is one of those renewable energy sources regarded as an option. However, the compatibility of the existing land resources for both productions is questionable.

To comply with these uncertainties about future food production, Luyten (1995) and Penning de Vries, Van Keulen & Rabbinge (1995) estimated the future global food production from suitable agricultural lands with the assumption of best technological application. They also indicated the availability of abundance of food at global level in the coming decades. However, it is found to be not in accordance with the existing situation, and further methodology should be devised that considers the present situation for the future prediction. On the other hand, Bruinsma (2003) estimated the rate of global food production and demand to 1.5 % per annum by usual trend yield increment. He also emphasized that, the present number of malnourished people in developing countries continues to decline to 400 million which may be attributable to high food consumption and reduced inequality. Hence, no significant self sufficiency is expected from his conclusion. The discrepancy in estimating the future potential food production is another reason to conduct this study.

Biofuel potential estimation is another important task that is given due consideration to estimate from the existing land resources in conjunction with food production. Wolf, Bindraban, Luyten & Vleeshouwers *(*2003) estimates the potential biofuel production following the route of Luyten (1995). They concluded that, 2.25 Gha of land can be available for biofuel production at the year 2050. Smeets, Faaij & Turkenburg (2007) claims the global bioenergy supply from surplus agricultural lands to 215-1272 EJ per year at 2050 if advanced biotechnology is applied. On the contrary, Nonhebel (2005) concluded the unavailability of land for biofuel production by consideration of global crops yield and consumption pattern. Nevertheless, the differences in estimation may emanate from the difference in methodologies used. This is analyzed in detail and indicated

by Berndes, Hoogwijk & Broek (2003) in a review of 17 studies on potential biofuel production estimation.
However, none or a few of the studies gave attention to the present situation for future prediction on potential food production estimation and to liquid biofuel production that is claimed to be substitute for fossil fuel. Furthermore, none of the studies were critically concerned about the competition between biofuel and food consumption focusing only on the energy crops that can be shared among both. Hence, this study investigates the future potential food production with the consideration of the present yield for the future prediction with the plausible food demand that can be acceptable to everybody. Therefore, it contributes reasonable estimation to future potential food production and liquid biofuel from surplus agricultural lands without compromising food demand.

1.2 Aim of the research

The aim of this study is to assess the global potential food production and demand, and hence to determine the possibility for biofuel production from surplus agricultural lands

1.3 Research question

Main question: Is there any possibility for biofuel production without affecting food consumption?

Sub questions:

1. How much food do we produce and do we need at present and in 2025?
2. Is there surplus land for biofuel production?
3. How much biofuel can we produce from surplus agricultural land at present and in 2025?
4. To what extent can biofuel production contribute to future global energy demand?

1.4 Boundary setting

This study only analyses the liquid biofuel (ethanol and biodiesel) excluding solid biomass energy and second generation biofuel which can be produced from waste matter and non-crop feedstock sources due to their irrelevance to the aim of the study. But also it excludes the potential production of biofuel on water bodies. The climatic suitability of each energy crops is also another factor which was intended not to be considered in to the analysis in order to avoid the complexity of the study. Our Scenarios also did not incorporate government policy and socioeconomic factors as there is as yet no global agricultural policy and standardized socioeconomic levels. Despite that, those incorporated inputs for the scenarios and other variables reinforce the result of the study.

CHAPTER 2: DATA AND METHODS USED

2.1 General overview of the methodology

The estimation of food production is categorized as present and future. To carry out the estimation the global land is divided in to 14 regions according to UN (1992). In all estimations the available agricultural land (arable and pasture lands) are accounted for. The population data is taken from UN population study databases for the present (2007) and for the future (2025).

The present food production is estimated from FAO present production databases. The estimation is carried out with 7 different kinds of crop groups and 5 different kinds of animal products. The future potential production estimation begins with the determination of the lower and upper limits. For the lower limit potential production, the arable land and the pasture land are allocated for crop and meat (beef) productions respectively. The upper limit potential production is estimated with the allocation of 75% of the available agricultural land to food crops production. It is assumed that the pasture land yields similar production as that of arable land. Here for the upper extreme determination, the present yield is expected to be doubled at 2025. Then after, the moderate scenario is developed within the range of the lower and the upper limits production potentials. Accordingly three scenarios are developed: lowest possible scenario (LPS), moderate and highest scenarios (see detail below).

All the present and future potential production is converted to grain equivalent to include the different composition of human diets. The different conversion factors of different food items are described in detail below. This conversion is very important to compare different productions according to their values in food i.e. grain equivalent is the value of the food items used as a raw materials to a certain food items. Then, all the productions are added to indicate the regional production potential in grain equivalent.

The regional food requirement is estimated from the total population of the present and future with three different kinds of diets. These diets are vegetarian, moderate and affluent diets. To help to secure the demand, the production-demand ratio of two is used. The doubling of demand is used to overcome the expected shortage of food due to yearly variation in production and loss on transportations. Therefore, it is assumed that the food is evenly distributed to everybody to satisfy the demand by producing or importing. Then the surplus food is extrapolated from this production-demand ratio to surplus agricultural land.

The potential biofuel production for the present and future is estimated from the surplus agricultural lands. Having only vegetarian food or affluent food all over the world is impossible and illogical. Therefore, in order to compromise this; the potential production is estimated from surplus land with a moderate diet, because the latter contains the necessary diets from plant and animals. To make efficient the production, different energy crops are analyzed according to their amount of energy production. But we also extend our estimation to biodiesel production from Jatropha on tropical and sub-tropical degraded lands. Details about the methodology are described below under each section.

2.2 Global population and land division

The global land area is divided into 14 regions according to UN (1992) population division. Some of the regions are merged with the expectation of no significant change to result. Accordingly, Northern Europe, Southern Europe, Eastern Europe and Western Europe are merged as Europe. These 14 regions differ significantly in many aspects. Agro-ecological conditions and socioeconomic status is among some features. Hence, the level of production of each region is not compromised by the effect of other regions.

Available agricultural land (arable land and pasture land) is considered for the estimation of food production. Forest land which has the potential to be productive for agricultural production is excluded to maintain the ecosystem integrity. Arable land according to FAO includes kitchen gardens and temporary fallows, and may not be equal to the actual harvested land (FAO definition). The land categories schematically presented in fig.1 is intended to show the relationship, competition and strategic devised for food and biofuel production estimation.

Data regarding population is taken from UN population study online database. The 2007 regional total population is considered as present population in order to adjust with the available data sources. The projected population for 2025 is also retrieved from this database, and that year is assumed to be the nearest year to predict from the present production situation.

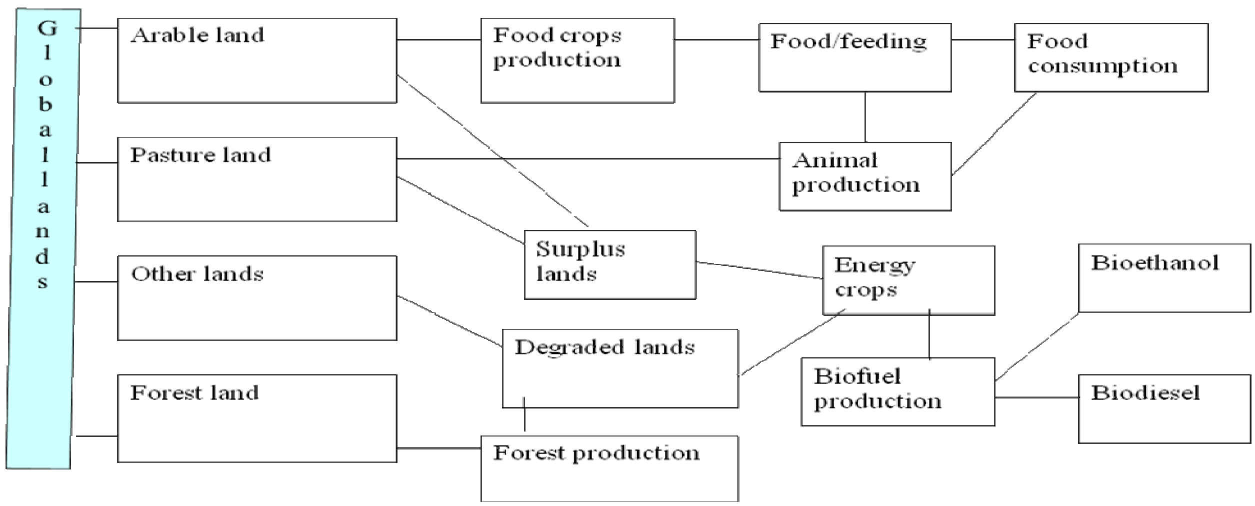

Fig.1 Schematic presentation of global land use devised for food and biofuel production

2.3 Global food production

2.3.1 Actual food production

The actual production data for food crops, meat and milk are taken from the United Nation Food and Agricultural organization online databases. Here after it is called FAOSTAT. Inclusion of each specific human food item into the calculation is difficult. Rather categorization of each specific crop according to their common characteristics and table 2 (the food items required for moderate diet) is considered. Hence, cereals, root and tubers, pulses, Vegetables, oil crops, fruits and sugar crops total production are considered for calculation. Coarse grains, wheat and rice are taken as cereal total with their average regional yields. These food items are the main composition of human diets and are considerably important for the actual estimation. Stimulant crops like coffee and tea are not included due to lack of data in this category from this database and the less importance in food demand estimation.

For actual animal products; beef, mutton, pork, milk and poultry are considered. Meat production from other sources is not considered, because those meats are the major meat consumed commonly all over the world with some exceptions for beef in India and pork among some religious peoples. The actual meat production is calculated irrespective of the land requirements due to unavailability of data on pasture land production i.e. no system of production is provided by this data source. The consumable carcass weight is only considered for estimation.

2.3.2 Scenarios

The future global food production estimation is carried out by three scenarios. These scenarios are devised depending up on the available agricultural land and system of production exploited. Thus, they are named as lowest possible scenario (LPS), moderate scenario and highest scenarios. Excel spread sheet modelling is used for calculation.

2.3.2.1 Lowest possible scenario (LPS)

Lowest possible scenario (LPS) is the minimum food production expected from available agricultural land with the exploitation of arable and pasture land separately with minimum yield. It is considered to be the lowest possibility to estimate the future potential production. Here the available agricultural land (arable and pasture land) is allocated to food crops and to meat production respectively.

2.3.2.1.1 Food crops production

The present arable land which is 1.6 Gha remains constant except the increment of yields of crops as usual trends. The usual trend yield increment data is taken from Bruinsma (2003) for the year 2025. The usual trend yield increment is the predicted increase of yield from the previous increase annual production. Thus for food crops production, the five years (2003-2007) average yield of common grown crop of the region is projected using the predicted yield increment. It is assumed that these most commonly grown crops can represent the regional total production and that they cover more than 50% of the regional harvested land.

2.3.2.1.2 Meat production

No data is provided by FAO on livestock production from pasture land. Livestock production on pasture land is one of the current problems in estimating how much the pasture land can produce. Because the extent by which the grass converted to a certain animal products depends on the type of grass, animal capacity to convert it efficiently and the yield of grasses. Hence, the data provided by Bouwman, Hoek, Eickhout & Soenario (2005) on pasture land is found to be relevant and valid for this study. They used an IMAGE model to draw out the world livestock production according to regional productivities. They incorporated the FAO actual data and data provided by Sere and Steinfeld (1996) and Bruinsma (2003) into the model. They also used some scientific assumptions and rearrangements to the data provided by Sere and Steinfeld (1996) and by Bruinsma (2003). They combined information on animal population and production characteristics, feed conversion and the composition of animal feed, and geographical information on the distribution of grassland for the period of 1970-2030. Ecosystem, crop and land use models are used to compute land use on the bases of the regional consumption, production and trading of food, animal feed, fodder, grass and local climatic and terrain properties. It is believed that for the provided data production the important aspects are incorporated which can subsequently validate this study. In addition, it is the only data source available online according to regional productivities.

The described data source also provides similar data on regional pasture land, but we opt to use the FAO data on pasture land for the sake of uniformity across this study. The feed conversion factor for each region is considered. The conversion efficiency for Europe is adjusted to North American conversion efficiency due to absence of data on pastoral system at this region, because we assume that both have similar climatic and economic situation. Data for the Caribbean region is not available and is therefore adjusted to the average of central and South American regions.

The data provided for Japan and Eastern Europe is included to East Asia and west Europe respectively. The regional grass yield per hectare is calculated from the land used and grass production data's provided in the projection.

Great regional variation was observed on the conversion efficiency of the grass to meat and milk (Table 1). In East Africa the efficiency of conversion to beef exceeds 100 kg of dry matter of grass per kg of the product while in North America and Europe is 33 Kg per kg of the product. The conversion efficiency to mutton in South America exceeds 60 kg of dry matter of grass while in North Africa it is less than 15 kg of dry matter per kg of mutton. On the other hand the conversion efficiency to beef in South America, Central America and Caribbean region is better than the conversion efficiency to mutton in these regions. A higher efficiency was observed to mutton than beef in aggregate at global level. This regional great variation may be attributed to the energy content of the dry matter used to maintain and gain the animal weight and may be on the species of the animal. Despite the great regional variation, the regional conversion efficiency of grass to meat and milk is used to estimate the regional production from the total grass produced at each region.

One commonly focused purely on pastoral system of production, because, including feeding from other sources does not tell us how much we can produce from pasture land. However, it is possible only to estimate the total beef or mutton or milk production from the total amount of pasture land to indicate the potential production of these animal products. Although we are restricted by unavailability of data on land division for each product, we can be able to compare global production efficiency of each product from their total production. Thus, only beef is considered for the estimation of the lowest potential production estimation from the total pasture land. The production of pork and poultry is now excluded since they are mostly landless. Both productions depend purely on the food crops. This is addressed in the highest scenario section of this study as an option for efficient meat production.

Table 1 Meat and milk conversion efficiency taken from Bouwman (2005)

Region	kg of dry matter per kg of beef	kg of dry matter per kg of mutton	kg of dry matter per kg of milk	kg of dry matter per kg of pork**	kg of dry matter per kg of poultry**
East Africa	111.4	17.2	4.5	6.6	4
North Africa	65.1	12.5	2.3	7.5	3.8
Southern Africa	72.7	22.3	5	6.6	4
Western Africa	88.9	17.3	4.6	6.6	4
North America	33.1	28.7	1.7	6.2	3.1
Central America	42.4	50.3	2.6	6.5	3.7
Caribbean	52.2	58.2	3.1	6.5	3.7
South America	64	64.6	3.5	6.4	3.7
Eastern Asia	55.2	21.3	4.6	6.5	3.3
South Asia	94.5	21.3	5.8	6.5	3.7
South eastern Asia	92	21.3	3	6.4	3.7
Western Asia	60.1	10	1.7	7	3.7
Europe	33.1	28.7	1.7	6.2	3.1
Oceania	41.4	31.7	1.9	6.2	3.1
World	67.9	25.6	3.6	6.4	3.4

*** Pork and poultry production is not part of the pasture land (pastoral system)*

2.3.2.1.2.1 Pasture land productivity variation and its impact on livestock production

Pasture land productivity variation is observed with regions. This variation is attributable to the climatic reliability of the region, length of rain fall, soil condition and the kind of grass grown (Sere and Steinfeld, 1996). The animal density and soil degradation is also another factor which can affect the pasture land productivity. Bouwman, Hoek, Eickhout & Soenario (2005) estimated grass production in Western Europe at 3 ton per hectare and even more (8-10 ton per hectare) for intensively managed grass lands; while for East Asia and East Africa with 0.5 and 1.5 ton per hectare respectively. This significant variation in grassland productivity has a great impact on the livestock density, because the carrying capacity depends on the quantity and quality of the dry matter to be fed to animals.

In their study Sere and Steinfeld, 1996 classified grass land productivity according to the agro-ecological zones. The agro-ecological zone is mainly designated according to the length of the rain fall season. Agro-ecological zones with more than 270 days of length of growing periods (LGP) categorized as humid, 181-270 days of LGP as semi-humid, 75-180 days of LGP as semi-arid and less than 75 LGP as arid. The estimation made for the grass land productivity and ruminant animals production for meat and milk depends on this agro-ecological zone variation and the type of the production system dominated in that particular climatic zones. Accordingly, the grazing system in OECD countries is intensified by high fertilizer application and irrigation whereas in most African and Asian countries it is the subsistence grazing system that is dependent on the rainy season.

The length of growing periods has significant effect on the productivity of the meat and dairy animals, especially in rain fed grassland systems. Significant weight loss is observed in rain fed grassland system of the humid high land east African regions. Another crucial constraint for the productivity of the animals for the meat and dairy production system is the agro-ecological climatic related problems of animal diseases. Due to these constraints the large majority of the grasslands left unproductive in some parts of the sub-humid tropics and sub-tropics low land regions. Another factor for the less productivity is the use of livestock for multipurpose (e.g. for farming) in sub-Saharan African countries. These agro-ecological climatic and socio-economic related factors are the main area of concern for which one life unit (1 LU) in tropical regions constitutes less than half of the temperate region animals. For instances the live stocking unit in sub-Saharan, north Africa and west Asia and other Asian regions are 0.46, 0.42 and 0.42 respectively to that of the temperate LU.

2.3.2.2 Moderate scenario

Moderate scenario is the scenario devised between minimum and maximum production potential characterized by expansion of the present arable land by 75% to pasture land. Currently, the great majority of global available agricultural land (3.4 Gha) is allocated to an inefficient production of meat (red meat). Therefore, shifting the production system to more efficient production, by extension of arable land to pasture land is devised in this analysis. An excel spread sheet is used for modelling. In this spread sheet modelling the arable land is extended by 75% to pasture land for which the rest of the pasture land is purely allocated to milk production albeit it is not enough to satisfy the required milk demand in all kind of diets. This allocation is with the assumption of allocating less land for less efficient production, because more land is needed for the production of meat. In addition we consider the impracticability of converting all the pasture land to arable land. Hence, the global arable land is extended to 4.12 Gha from the present 1.6 Gha. The increment in yield for cereal crop is taken from the existing usual trend yield increase (Bruinsma, 2003) and projected to 2025. A relatively higher yield increment is expected from developing countries in which the potential capacity is not exploited yet. The regional conversion efficiency and grass yield is used for milk production calculation (Table 1). The rest milk demand is designated to production from food crops.

Here the red meat production from ruminant animals (cattle, goat and sheep) is totally replaced by a more efficient and relatively landless production system (pork and poultry) to supply the necessary meat demand. The allocation to meat production using the landless system is also carried out depending on the share in the diet and higher energy value of the type of meat (Luyten, 1995). The energy value supplied by pork is triple that of poultry, and the share in moderate diet is the ratio of 10:1. Thus, in this substitution 75% of the meat production is assigned to pork and the rest 25% is to poultry. This calculation is adapted from the amount of per capita per year diet which is extrapolated to the total food demand and land requirement.

2.3.2.3 Highest Scenario

Highest scenario is the maximum scenario for which 75% of the present pasture land is converted to arable land with doubling of the present crop yield. All the parameters used in section 2.3.2.2 are kept constant except the crop yield. Increasing yield is another possibility of increasing production. This can be attained either by using irrigation or intensive farming system or both. However, we did not incorporate any farming system in our analysis. Nevertheless, high external input is opted to double the productivity of the present crop yield. It was shown that there is a yield variation with less than 1 ton per hectare in east and West Africa and more than 7 ton per hectare in North American regions (FAO; Kim et al., 2004). However, the potential production, in those regions with lower yield is high with the possibility to produce more than two times per year (Penning de Vries, Van Keulen & Rabbinge, 1995; J.C.Luyten, 1995). In addition, according to the study by Penning de Vries (1995), the high external input (HEI) productivity is double that of Lower external input (LEI). The HEI production system is an intensive farming system accompanied by intensive commercial fertilizer application and biocides. On the other hand the LEI system is devoid of the application of commercial fertilizer and biocides. The LEI yield is consistent with the current world average yield. Therefore, emanating from these essences; the production system in most parts of the world regions is considered to be similar to the LEI production. However, some of the regions especially the developed countries use high fertilizer application and biocides. Hence, with this consideration we projected the present yield with maximum delimitation of 7 ton per hectare of the North American average Maize yield. Except North American region, the present yield (2007) in entire regions with the annual yield of less than 7 ton per hectare is projected to be doubled at 2025. This highest yield in North America is not the only highest yield in the world. Highest yield of wheat in Ireland, Rice in Australia, sorghum in Israel and Jordan with more than 7 ton are also recorded (S. Kim et.al, 2004), but with low coverage. This doubling of the present yield is expected to be attained with the annual increase rate of 4.7%. It is considered that, even if in some developed regions the increase in yield seems to be saturated (Bruinsma, 2003) the development of crop biotechnology can be expected to foster the productivity.

2.4 Conversion to grain equivalent (GE)

All food productions under section 2.3 are converted to grain equivalent in order to make the products comparable and to incorporate the different composition of food items. It is a hypothetical weight unit which is frequently used by different researchers in the estimation of food production and consumption with different operational definitions. Even for the food production and consumption different definitions are given (Luyten, 1995). J.Wolf et al. (2003) defined it as a dry matter of a certain food items which can be used as a raw material for a certain products, i.e. plant, diary and meat products. Nevertheless, the definition by J.Wolf et al. (2003) and conversion factors by J.C.Luyten (1995) is considered to be of value for this study and is expressed in detail below.

GE is more expressed as a quality of a certain consumable food items used directly or indirectly as raw materials. It is computed depending on how much energy this food item can contribute to food relative to wheat. The relative value is expressed as a productivity index. There is a case at which some food items have more productivity index than the reference crop. For instance, some sugary crops with high energy content and food component and lower moisture contents have high productivity indexes (Penning de Vries, 1997). Tomatoes and other vegetables with high moisture content and lower energy content have very low productivity index (0.07) relative to wheat. As a reference crop, wheat has a value of 1, but as an average with other grains its GE conversion factor is adjusted to 0.7. Generally the conversion factor (CF) to GE depends on the moisture content of the fresh food item, the fraction of the food component of the product and the amount of grain needed to convert to a certain animal protein which also in turn depends on the animal's conversion efficiency. For instance 1 kg of potato contains only 0.4 kg of dry weight due to high moisture content of the product. In order to produce 1 kg of Cheese we need 14 kg of Milk, to produce 1 kg of milk we need 1.5 kg of grain. Therefore, the conversion factor for Cheese is set at 21 i.e. we need 21 kg of grain to produce 1 kg of cheese. The conversion factor to fat is set to zero as fat production is included in meat production. CF to produce white sugar from sugar beets equals 7.4 and similarly to potato, the conversion from sugar beets to cereal is set to 0.4, therefore, CF to produce sugar is 3.0. The oil content of oil crop varies with crops types, and the conversion factor is set to 3.0 (See table 2 below and J.C.Luyten, 1995). Therefore, the amount of grain equivalent in a kilogram of storage organ is computed as:

$$GE = \frac{Ec \times Fdm \times Fc}{Ecw \times Fcw}$$

GE = Grain equivalent of that specific food item
Ec = Energy content of that specific food item
Fdm = Dry matter content
Fc = Food component of that food item
Ecw = Energy content of wheat (16.3 MJ per Kg of wheat)
Fcw = food component of wheat (0.85)

In some cases the energy content of the protein in a certain food or food products are used (J.C.Luyten, 1995) in computing CF when more grain is needed to produce protein than energy. Accordingly, the conversion factor to milk, beef, and pork, chicken and egg is set to protein requirement depending on the animal conversion efficiency, because more grain (fodder) is needed to produce protein products than energy. The energy, moisture and the useable fraction of the crop as a food component determine the value of the conversion factor to GE. The energy content of poultry and egg is less than half of that of pork and beef. This less energy values in turn increases the amount of GE in kg of poultry and egg despite the more conversion efficiency of grain to poultry and egg than other animals' origin. On average 7.0, 6.4, 3.4 and 3.0 Kgs of grain is needed to produce a kg of beef, pork, and poultry and egg respectively (Bouwman et al., 2005; L.R.Brown et al., 1994). In contrast, the values of their conversion factor to grain equivalent is set at 5.3, 9.5, 6.3 and 11.1 for egg, poultry, pork and beef respectively due to their differential energy values (Table 2). The mutton included in the table is not part of a moderate diet; it is included only to show the CF to GE.

Table 2 Dietary compositions of moderate diet and conversion factors to Grain equivalent taken from Luyten (1995)

product	Consumption [g/d]	Energy value [KJ/kg]	Energy intake [KJ/d]	Protein content [%]	Protein intake [g/d]	CF [kg GE/kg product]	GE [g/d]
Cereals	491	8650	4247	7.6	37.3	0.7	344
Potato	420	3530	1483	2.0	8.4	0.4	168
Legumes	9	13350	120	22.0	2.0	0.4	4
Fruit	50	2240	112	0.7	0.4	2.0	100
Vegetable	100	1000	100	2.0	2.0	1.0	100
Sugar	24	16800	403	0.0	0.0	3.0	72
Veg-oil	40	31500	1260	0.0	0.0	3.0	120
Milk	408	2700	1102	3.4	13.9	1.5	612
Cheese	20	14450	289	31.1	6.2	14.0	280
Pwdrmilk	15	14540	218	34.0	5.1	17.0	255
Butter	10	31500	315	0.6	0.6	0.0	0
Egg	16	6340	101	13.3	2.1	5.3	85
Beef	14	11720	164	17.8	2.5	11.1	155
Pork	8	15580	125	13.8	1.1	6.3	50
Poultry	1	7140	7	20.0	0.2	9.5	10
Mutton		12900		16.4		9.8	
Total	1626	6178	10046	5.0	81.2	1.45	2355

2.5 Determination of food demand

Data for per capita per day for different diets is taken from J.C.Luyten (1995) in grain equivalent. Food demand is calculated from total population and per capita food consumption. However, the per capita food consumption varies with food consumption pattern. It is categorized as vegetarian, moderate and affluent diets. The vegetarian and moderate diets are deemed to be representative for a moderate consumption pattern and are satisfactory. The minimum caloric intake for an adult is 10 MJ and daily protein requirement is on average 1.0 g per kg body weight. Therefore, the daily requirement for an adult person comprises an energy intake of 10 MJ, to account for other nutritional requirements at least 12% of the energy is to be supplied in the form of animal or vegetable protein, less than 30% as fat. The basic caloric intake is the same for all the diets, but the content of the animal protein increases from vegetarian to affluent diets. Depending on the nutritional requirements, regardless of the dietary constituents; the vegetarian diet is considered to be the minimum and the affluent diet is the maximum requirements.

The diets are composed of plant, dairy and meat products converted according to its specific conversion factor to grain equivalent. Those conversion factors are the weighted averages of the conversion factors of the various food items included in each categories of the diet (see table 3). The amount of grain required for affluent diet is almost four times greater than that of vegetarian diet, and it is set at 1.3, 2.4 and 4.2 kg GE (dry matter) per day per person for vegetarian, moderate and affluent diets respectively. The basic caloric intake in both vegetarian and moderate diets is almost similar [10 MJd^{-1}] with minor variation with affluent diet [11.5 MJd^{-1}]. The huge variation exists on the kind of protein sources taken in food. In vegetarian diet the source of protein content is mostly from plant origin and for the moderate and affluent diet it is from plant and animal origin. The net protein intake does not show great variation, but great variation exists on the grain needed to produce the animal protein. Affluent diet needs high amount of grain to produce the high amount of animal product in the diet.

Shifting of diet to less animal origin depends on the willingness of the consumers and is difficult to decide. Nevertheless, for the purpose of this research only the moderate diet is considered for all the regions with the assumption that it is the medium diet to vegetarian and affluent diets and can fulfil the basic necessary dietary requirements from plants and animal products.

Table 3: The basic requirement values for vegetarian, moderate and affluent diets taken from Luyten (1995)

Diets	Consumption [gd^{-1}]	Energy in-take[KJd^{-1}]	Protein intake [gd-1]	CF [kg GE/kg prod]	GE [gd^{-1}]
Vegetarian diet					
Plant products	1355	9356	66.7	0.8	1053
Dairy products	122	693	8.6	2.6	286
Total	1457	10049	75.3	0.92	1339
Moderate diet					
Plant products	1134	7725	50.0	0.8	908
Meat products	23	296	3.8	9.4	215
Dairy products	469	2025	27.4	2.4	1232
Total	1626	10046	81.2	1.45	2355
Affluent diet					
Plant products	938	6685	28.9	1.2	1138
Meat products	225	2843	36.7	8.5	1907
Dairy products	354	2013	26.5	3.3	1161
Total	1517	11540	92.1	2.77	4206

2.6 Determination of surplus agricultural land

Surplus agricultural land is extrapolated from the existing surplus foods after satisfying the food requirement with moderate diet. The surplus food is calculated from the production demand ratio of 2. The doubling of demand is used to overcome the expected shortage of food due to yearly variation in production and loss on transportations. Therefore, it is assumed that, the food is evenly distributed to everybody by producing or importing to satisfy the demand with this diet. Therefore, the estimated surplus agricultural land at global level is deemed to be of value for the estimation of global biofuel production.

2.7 Biofuel production

Biofuel production estimation is undertaken from surplus agricultural land. In addition, production from degraded land is also conducted despite its irrelevancy to compete with food crops and agricultural land. Production of biofuel is categorized as bioethanol and biodiesel depending on the energy crops deployed for their production.

2.7.1 Production from surplus agricultural land

The surplus land after satisfying the demand for moderate diet is used for biofuel production both in present and future situations. The present production here assumed as a scenario, because different diets are already in use. The extrapolated surplus land potential production is estimated with the efficient biofuel production from specific energy crops of high energy contents and yields. Hence, the energy crop(s) with high amount of production is considered, because efficiency according to this study is only concerned with the total amount of biofuel produced.

To comply with the efficient production; some energy crops like Maize and wheat for ethanol production with the intention that they can be grow in temperate and tropical climates. Sugarcane is also considered for its potential production in tropical and sub-tropical and sugar beet for temperate regions ethanol production. Rapeseed and Jatropha is considered for biodiesel production (Fig.2) depending on the climatic suitability for these crops. For instance rapeseed can produce 382 litre of oil per ton of seed in temperate climate (Cesar *et al*., 2007). Jatropha is much productive in tropical climate with high energy content on less productive lands with yield of 1590 Kg of oil per hectare (Mathew, 2007). The estimation of the potential production is carried out according to their sugar content converted to bioethanol or oil content converted to biodiesel (Table 4).

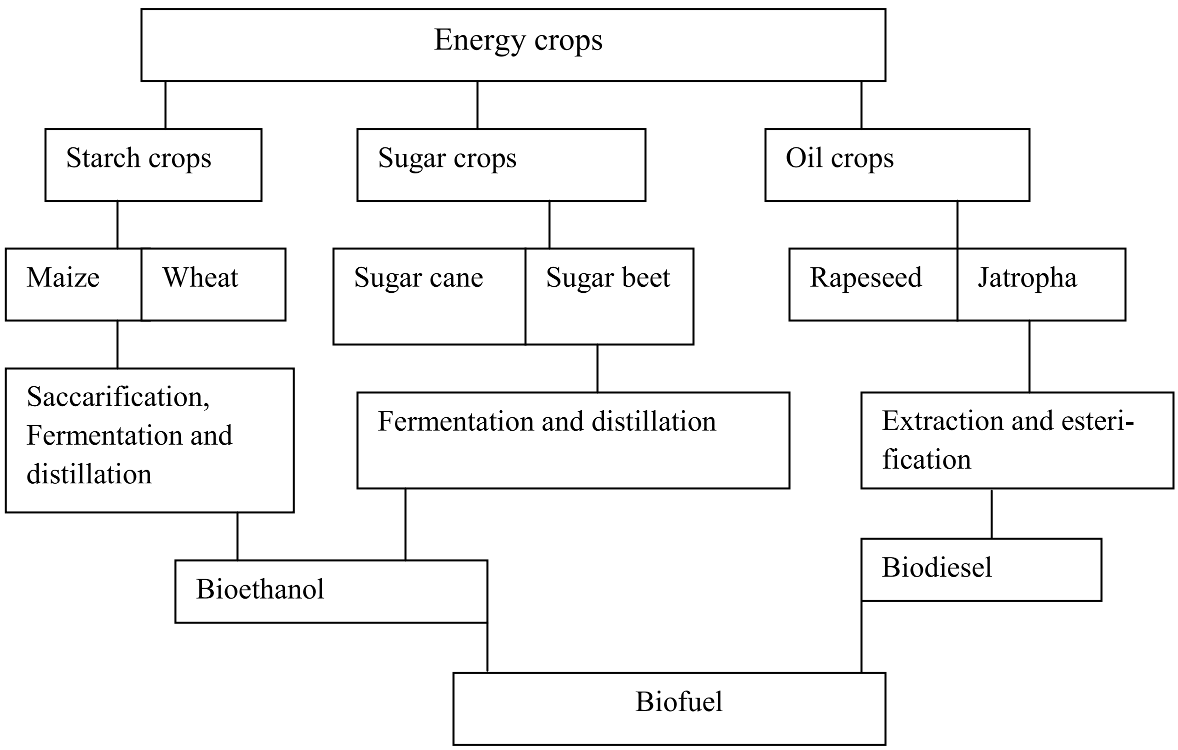

Fig. 2: Schematic presentation of the process of energy crops conversion to liquid biofuel

Data regarding energy crops yield per hectare is taken from FAOSTAT except for Jatropha, and doubled for the year 2025 in the same manner as food production estimation. Jatropha is an inedible energy crop and is a candidate for biodiesel production (see section 4.7.2). The amount of biofuel per ton of energy crops is taken from Gui *et al.* (2008); Venturi et al. (2003); Rajagopal *et al.* (2007). It is shown that the value for bioethanol production from starch and sugar crop are estimated from fermentable carbohydrate content of the crops, while for biodiesel the oil content of the energy crop is accounted (Gui *et al.,* 2008*)*. The energy content of all the energy crops is estimated from the energy content of bioethanol and biodiesel (Xiaoyu Yan *et al.*, 2008; Agarwal et *al.*, 2007; Carraretto *et al.*, 2004). Because all the energy crops end product according to this study is either bioethanol or biodiesel, and their value is set to 23.1 and 33.5 MJ/litre of bioethanol and biodiesel respectively (Table 4).

Table 4: data for calculation taken from Kim et al. (2004); GUI Et Al. (2008); Venturi et al. (2003); Rajagopal et al. (2007)

Energy crops	Yield ton/ha	Biofuel (l/ton)	Energy (MJ/l)	remark
Wheat	2.8	340	23.1	bioethanol
Maize	4.6	400	23.1	‘”
Sugarcane	65.3	70	23.1	”
Sugar beet	42.6	110	23.1	”
Rapeseed	1.7	400**	33.5	biodiesel
Jatropha	2.5*	350**	33.5	”

*****_The yield is taken from W.M.J. Achtena et.al, 2008, average of degraded land yield_
**calculated from % of oil content

2.7.2 Production from degraded lands

Production of biofuel on degraded agricultural lands as a result of human action is also another additional option. This land category is classified as other lands (FAO definition). It is categorized to be unproductive for food production. However, it was shown that some energy crops are productive with minimum or without external input like fertilizer and biocides (Achtena *et al.*, 2008*)*. Data regarding regional land degradation is taken from global assessment of human induced land degradation (GLASOD) databases. The data is provided with the degree of degradation as slight, moderate, strong and severe (see definition by Oldeman *et al.*, 1991). The data seems to be old enough and may not be representative for the present situation. However, we consider it as a minimum degraded lands depending up on the increasing in degradation and decided to be valuable for this study. The study by the world soil information centre (ISRIC, 2008) indicate that, the extent of degradation provided by GLASOD increased from its 15% to current 24% of global degradation (Bai *et al.,* 2008). This study by Bai *et al. (*2008) seems to be recent, but provides the total global degradation according to countries of the world. It does not indicate according to its degree of degradation like GLASOD. All degraded lands including the severely degraded land which is not required for this study are also included. Then, GLASOD data is opted to be used as a minimum degraded land albeit it seems out of date. Hence, we consider the slightly and moderately degraded lands by accounting the economic feasibility on production. Therefore, exploitation of degraded land for this purpose is very crucial especially in tropical and sub-tropical regions where certain non-edible energy crops like Jatropha are productive with or without external inputs. Its yield varies depending up on the Jatropha trees age, rain fall, soil type and the tree management, and ranges from 1.5-7.8 dry seed per hectare per year (Achtena *et al.,* 2008). Depending on our purpose that we are intending to calculate the production on degraded land we used the productivity from degraded land. The degraded lands in temperate regions are not considered in this study due to unavailability of data on energy crops suitable for such soil type and climatic condition.

CHAPTER 3: RESULTS

3.1 Global food production and demand

3.1.1 Global present food production and demand

According to FAOSTAT the actual food production was calculated to be 7.2 Gt GE. This amount represents the total food crops harvested in the year 2007 from total harvested lands and the total meats produced in the year. The produced food cannot satisfy the demand with moderate diet. This does not mean that everybody over the globe demand moderate diet at present, it is just a scenario. The total production in grain equivalent with its corresponding demand for vegetarian, moderate and affluent diets is shown (Table 5).

Comparatively, some regions are within the shortage of food with vegetarian and moderate diets. East Africa, North Africa, West Africa, Caribbean, South-Central Asia, South-East Asia and West Asian regions are those regions that are unable to feed themselves with vegetarian or moderate diet if everybody in these regions is supposed to consume vegetarian or moderate diet. Especially south-Central Asia with more than one fifth of the world population and sub-Saharan countries with high population growth rate and subsistence farming have extreme food shortage with these diets. On the other hand, excess in production is observed in some developed regions. North America, South America, Europe and Oceania produced surplus food with moderate diet. This excess food is attributable to the high yield and low population growth rate of the regions. However, no region except Oceania can feed all its population with an affluent diet with the present production. In general, no surplus agricultural land is available at global level satisfying the demands with moderate diet with present production.

Table 5 Global actual food production and demand in 2007

Regions	Total population 2007 [1000]	Total food production [Gt GE]	Total food demand with different diets [GE Gtonnes]		
			vegetarian	moderate	affluent
E.Africa	297539	0.12	0.28	0.52	0.96
N.Africa	200690	0.15	0.19	0.35	0.62
S.Africa	55500	0.05	0.05	0.10	0.17
W.Africa	393010	0.17	0.37	0.69	1.20
N.America	332975	0.95	0.32	0.58	1.02
C.America	146775	0.17	0.14	0.26	0.45
Carbbean	40925	0.03	0.04	0.07	0.13
S.America	378679	0.76	0.36	0.66	1.16
E.Asia	1563472	1.80	1.48	2.73	4.79
S.C.Asia	1656790	0.94	1.57	2.89	5.08
S.E.Asia	558669	0.40	0.53	0.97	1.71
W.Asia	215088	0.19	0.20	0.38	0.66
Europe	734087	1.35	0.70	1.28	2.25
Oceania	33710	0.15	0.03	0.06	0.10
World	6607909	7.22	6.27	11.52	19.80

3.1.2 Future food production and demand

3.1.2.1 Future food production with lowest possible scenario (LPS)

The global food production with this scenario is carried out on global arable and pasture lands separately. Thus, the value of production displayed in table 6 is in grain equivalent to make comparable the two productions. Here the agricultural area used for meat production is more than twice the land used for crop production. In total, at global level, 5.87 and 0.85 gt grain equivalent of crop and beef can be produced respectively. In total only 6.7 gt grain equivalents with its assumed corresponding moderate diet of 12.6 gt grain equivalents (see table 6). This value is less than the present production due to the fact that, more production at present comes from animal products which might be produced using food crops and agricultural residues.

Great regional variation in crops and meat production is observed. Crop production in East and West African and Caribbean regions is very discouraging due to extremely low yields. However, excess amount of production is observed in regions with high yields per hectare of arable land. Great regional variation is also observed on meat production due to differences in conversion factors to animal products and variation in grass yields. The amount of dry matter required to produce a certain amount of animal product varies with regions. This great variation in conversion factors may be due to the variation in the quality of grass and animal's species and health condition.

Table 6 Food production with lowest possible scenario in various regions of the world in 2025

Regions	Total population [1000] 2025	Crop production in Gt GE per year	beef in Gt GE per year	total food production in Gt GE per year	Total demand Gt GE per year
E.Africa	465394	0.08	0.02	0.10	0.73
N.Africa	254557	0.12	0.01	0.13	0.42
S.Africa	60577	0.05	0.01	0.06	0.09
W.Wfrica	613344	0.10	0.02	0.12	0.98
N.America	392978	1.62	0.09	1.71	0.54
C.America	180108	0.09	0.03	0.12	0.29
Caribbean	47144	0.01	0.00	0.01	0.09
S.America	460777	0.43	0.15	0.58	0.6
E.Asia	1653595	0.93	0.06	0.99	2.78
S.C.Asia	2145999	0.87	0.24	1.12	3.35
S.E.Asia	686251	0.34	0.01	0.35	1.14
W.Asia	293144	0.13	0.01	0.13	0.47
Europe	715220	0.99	0.15	1.15	1.04
Oceania	41421	0.11	0.04	0.15	0.01
World	8010509	5.87	0.85	6.73	12.55

3.1.2.2 Future food production and demand with moderate and highest scenarios

High production potential is observed in the moderate scenario only by increasing of arable land and shifting meat production to white meats. It indicates how much the meat production from pasture land is inefficient. The total production amount is doubled compared to lowest possible scenario (table 7). The regional production variation observed in this scenario attributes to the initially available area of regional pasture land and yields of crops. In Eastern Asia the production in moderate scenario is triple that in LPS. In this region, before expansion to pasture land, the arable land only shares 23% of the available agricultural lands compared to the average (32%) global arable land share. Similar result also observed in Oceania and South American regions.

With another scenario the potential production is also estimated with doubling of the present yield. In the previous two scenarios the usual trend increase was assumed. However, in this scenario, the present yield is doubled in addition to shifting of the meat production from red meat (meats from cattle, sheep and goat) to white meats (meat from pig and poultry). Similarly, the later parameter also applied in moderate scenario too. Hence, the total production is estimated at 19.5 Gt grain equivalents. The estimated production in this scenario is by far less than the estimation made by Penning de Vries (1995) and Hoogwijk *et al*. (2005) in HEI production system. They estimated 72 and 35.6 GTS grain equivalent respectively. Because their estimation depends on the land suitability for modern farming, it is not based on the present regional yields. In this study the yield of seven tonnes per hectare is assumed as a maximum delimitation, but in their estimation they estimated 16-20 tonnes per hectare for tropical irrigated lands. The global potential food production and demand for different regions is shown in table 7.

Table 7 Future food production and demand in various regions of the world at 2025

Regions	Total 2025 population [1000]	scenarios of food production [Gt GE per year]			food demand [Gt GE per year]		
		LPS	Moderate	Highest	vegetarian	moderate	affluent
E.Africa	465394	0.10	0.34	0.44	0.34	0.73	1.28
N.Africa	254557	0.13	0.51	0.74	0.20	0.42	0.72
S.Africa	60577	0.06	0.39	0.51	0.04	0.09	0.17
W.Africa	613344	0.12	0.32	0.42	0.46	0.98	1.71
N.America	392978	1.71	3.02	3.02	0.21	0.54	1.01
C.America	180108	0.12	0.27	0.39	0.12	0.29	0.70
Carbbean	47144	0.01	0.02	0.02	0.04	0.09	0.27
S.America	460777	0.58	1.73	2.48	0.21	0.60	1.14
E.Asia	1653595	0.99	3.16	3.82	1.38	2.78	4.73
S.C.Asia	2145999	1.12	1.83	2.46	1.53	3.35	5.88
S.E.Asia	686251	0.35	0.40	0.58	0.56	1.14	1.95
W.Asia	293144	0.13	0.56	0.82	0.22	0.47	0.82
Europe	715220	1.15	1.55	2.66	0.43	1.04	1.88
Oceania	41421	0.15	0.76	1.09	0.02	0.01	0.06
World	8010509	6.73	14.86	19.46	7.60	12.55	22.33

3.2 Global surplus agricultural land

In order to provide general insight, the production is analyzed with three different diets (vegetarian, moderate and affluent), but potential surplus agricultural land estimated only with moderate diet. The total production, demand and surplus food at global level is shown (Fig.3). The production potential increases from the lowest possible to the highest scenarios. In the same manner the corresponding demand also extremely increases from vegetarian to affluent diets. However, the amount of maximum demand (affluent diet) outweighs its corresponding maximum production at highest scenario. Thus, no global surplus agricultural land is available with affluent diets in all scenarios. In addition, the analysis also indicates no surplus land at present and LPS if everybody consumes moderate diet. Nevertheless, with the highest scenarios, if everybody demands a moderate diet, 2.3 Gha of surplus agricultural land can be available for biofuel production (Table 8). The available surplus land in the highest scenario seems to be high, because the area of land required to produce the amount of food demand reduces due to the assumed high yield. Thus, doubling of the yield in this scenario reduces the amount of land required to produce food consumption in moderate scenario from 4.2 Gha to 2.7 Gha.

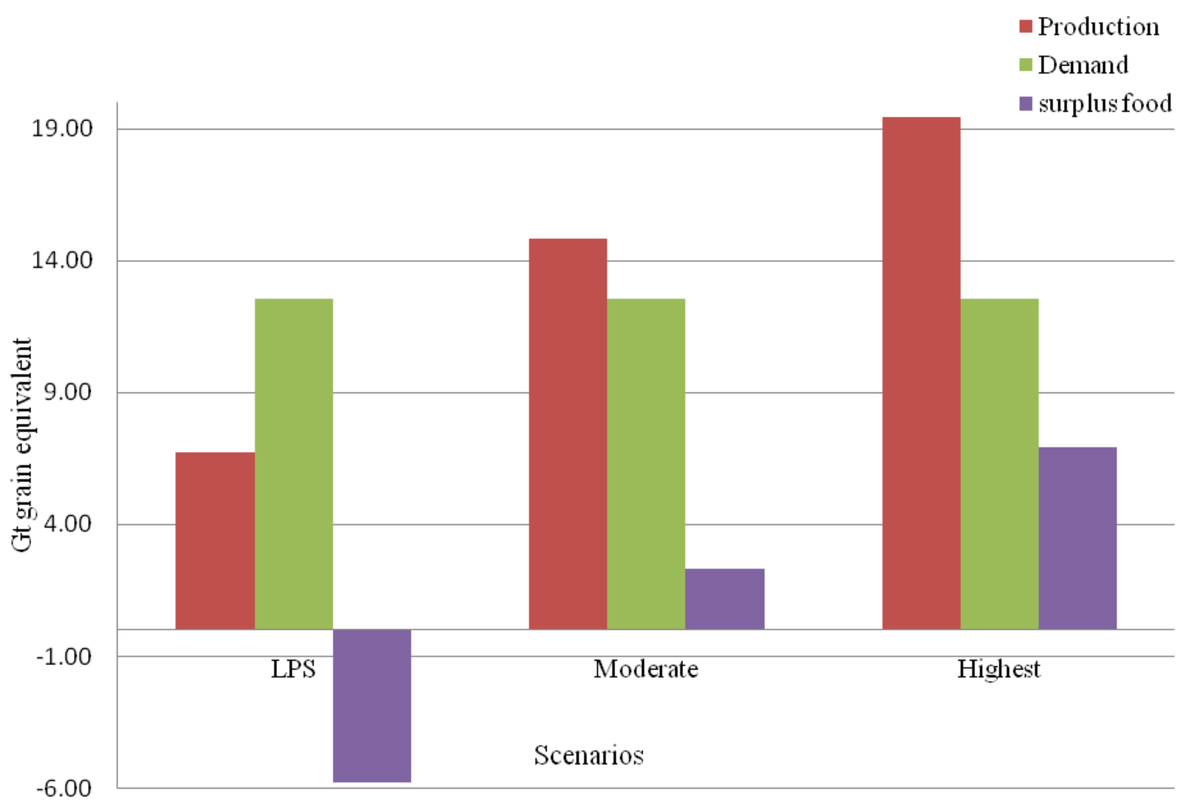

Fig.3 Global potential food production, moderate demand and surplus food in 2025

Table 8 Globally available surplus agricultural land with moderate diet in 2025

Category	surplus agricultural land (Gha)
present	0
Lowest possible scenario (LPS)	0
Moderate scenario	0.75
Highest scenario	2.3

3.3 Biofuel production

3.3.1 Biofuel production from surplus agricultural lands

Surplus agricultural land in table 7 is dedicated for biofuel production after the demand for food is securely satisfied. Different energy crops stated in section 2.7.1 are used for estimation of potential biofuel production. Here we introduced the term efficient production. Efficient production consideration according to this study is with respect to the total amount of biofuel produced from a certain energy crop relative to another one from the same land. Accordingly, sugar cane and sugar beet are found to be the best energy crops with highest production of bioethanol relative to biodiesel production from Jatropha and Rapeseed (Table 9). At present and with LPS, production of biofuel is unlikely. However, with the moderate and highest scenario, the potential biofuel production is estimated to be 0.2 EJ and 0.9 EJ of energy per annum from bioethanol or 0.03 EJ and 0.2 EJ of energy per annum from biodiesel respectively (Table 9). Nevertheless, with the consideration of efficient and maximum production, the global potential energy production from biofuel is adjusted to 0.9 EJ of energy per annum.

Table 9 Global biofuel production from surplus agricultural lands at present and in 2025

	Sugar cane and sugar beet	Jatropha and rapeseed
Category	Energy from bioethanol in (EJ)	Energy from biodiesel in (EJ)
Present	0	0
LPS	0	0
Moderate	0.2	0.03
Highest	0.9	0.2

3.3.2 Biofuel production from degraded land

Biofuel production from degraded land is not part of production from surplus agricultural land. It is calculated to show as an option of possibility of producing first generation biofuel using other land resource. This kind of production is very important in tropical regions where surplus agricultural land is unlikely. Hence, it is only estimated to tropical and sub-tropical regions due to lack of data on energy crops particularly suitable to temperate degraded lands. Accordingly, North American, Europe and East Asian regions are excluded from the estimation. Thus, the production for the rest of the regions is estimated from Jatropha plantation and is estimated to be 2.88 Gl of biodiesel or 0.09 EJ of energy per year (Table 10). This production is very important to African regions with no or little surplus agricultural lands with present yields; and with high land degradation. Particularly East Africa and West Africa regions with high food shortage even with highest scenario are estimated to be in the top five regions with high production of biodiesel on degraded land. However, the highest production is observed in South American region (0.82 Gl). West Africa and East Africa are listed to third and fourth with 0.41 Gl and 0.34 Gl of biodiesel per annum respectively. The observed highest production is with respect to the amount of available degraded land.

Table 10 Potential biofuel production from degraded lands at various tropical and sub-tropical regions

Regions	Degraded lands [10^{-3} Gha]	Jatropha Production [10^{-3} Gt per year]	Biodiesel production [Gl per year]
E.Africa	0.39	0.98	0.34
N.Africa	0.22	0.55	0.19
S.Africa	0.07	0.17	0.06
W.Africa	0.47	1.17	0.41
C.America	0.04	0.10	0.04
Carbbean	0.01	0.02	0.01
S.America	0.94	2.35	0.82
S.E.Asia	0.21	0.53	0.18
S.C.Asia	0.28	0.71	0.25
W.Asia	0.18	0.46	0.16
Oceania	0.47	1.19	0.42
Total	3.29	8.21	2.88

CHAPTER 4: DISCUSSION

The reliability from this study was analyzed. First uncertainties in the major assumptions which may affect the calculated global food supply and requirements and thus the potentially available area for energy crops production were discussed. Second, the regional difference in potential production of food was focused on. Third, the potential production of food and biofuel were compared with other studies. Fourth, the potential contribution of biofuel to future energy demand was discussed. Lastly, the significance of biofuel production from degraded land was discoursed.

4.1 Uncertainties in the major assumptions of this study

The potential food production is the product of the available agricultural area and crops yield per area of land. All the regionally available agricultural land is considered to be equally productive according to this study. This assumption was from two angles. First, the pasture land is not assumed to be productive like arable land, but it is a fact that, the pasture land in developed regions is as productive as arable land due to intensification of pasture lands. Second the arable land in subsistence farming system is assumed to be relatively less productive and may not be significantly more productive than its adjacent pasture land. Therefore, with these considerations, the potential production according to the region does not affect the total result. However, the main significant assumption left uncertain is shifting the meat production to monogastric animals. This is totally dependent on the people's willingness to change their meat production system and consumption preferences. Even though, the general features of quality of meat depends on its nutritional value, safety and suitability to prepare and to eat, most people may prefer red meat over pork and it is difficult to shift to pork. Studies show that, Pork is perceived to be worst as compared to beef and poultry on the attributes leanness, healthiness, taste and tenderness (Verbeke et al., 1999; Grunert, 1997). Another problem is shifting to white meats is the religion issue. Consuming pork is considered a sin among most religious peoples. These main two factors may affect the implementation of the intended production system due to uncertainty in the shifting of meat consumption. However, given great consideration to policy of livestock production, intensive advocacy and globalization may uproot these socio-cultural constraints. If the policy of livestock production focuses on a system of production with prompt education, the people may start to shift their diet. Globalization of trading and food acculturation is also another strategy to adopt and practice. However, these constraints do not have an effect on the estimation of the potential production; it is the problem of application.

Doubling of the present yield for the maximum potential production scenario was assumed. This assumption was based on the present regional yield. In order to avoid the yearly variation in yield, the five-year average yield of common grown crop in the region was accounted for. Crops which cover more than 50% of the total harvested land are considered the most commonly grown crop of the region. This can tackle the uncertainty which might appear on the total production due to variation in yield among different crops and climatic adaptability of the crop. In addition, the assumed highest yield at 7 ton per hectare may not consider as a highest unattainable yield, because some regions already attain at present (Kim *et al*., 2004; FAOSTAT). It is also optimistically considered that, the present yield in subsistence farming system can easily be boosted with minimum input to attain a double output. Studies indicated that most of the regions with the lowest yield at present have great potential if irrigation is applied and agricultural technology is introduced (Penning de Vries, 1995, Luyten, 1995). Therefore, the assumed yield in highest scenario can be an attainable yield which can validate the result of this study.

4.2 Regional differences in potential food production

The result of this study indicates great regional potential production variation. The amount of food needed also varies depending on the regional total population, which can determine the amount of surplus food. In some regions, the potential production was observed to be very low even with the maximum production scenario (table 11). Here the available arable land is expanded to its maximum by 75% with doubling of the present yield. Nevertheless, high regional shortage of food is observed in regions with the initially lower yield, high population growth rate and lower per capita agricultural land. East Africa, West Africa and the Caribbean are regions with already a lower present yield and high population growth rate estimated that can experience high shortage of food with moderate diet. In these regions, the initial present yield was less than 1 ton per hectare per year (FAO) with a population growth rate of 2.4% per year (UN population division). Thus, doubling of the yield and expansion of agricultural land does not contribute significantly to food self sufficiency. Another, shortage was also observed at South-central and south-eastern Asian regions. South-central Asia feeds approximately 25% of the world population with 0.29 hectare per person agricultural land, and South-Eastern Asia with 0.17 hectare per person agricultural land (table 11). In contrast, the production potential in some regions is extremely high. For instances, the highest production potential observed in eastern Asia is due to initially high yield and relatively high potentially available pasture land in the region. Only 23% of the available agricultural land in this region was initially used for arable land compared to the 32% of the average global arable land. The potentially large area of pasture land expanded to be arable land boosted the maximum potential production of this region as well as that of the North American and Oceania regions.

Table 11 Global and regional total population, total agricultural land and per capita per person land, projected yield, food production, demand and surplus food in 2025.

Regions	total population 2025[1000]	total agricultural land (1000 ha)	per capita land (ha/person)	yield in ton/ha GE	food production [gt GE]	moderate diet [gt GE]	Surplus food [gt GE]
E.Africa	465394	301702	0.72	1.75	0.44	0.73	-0.29
N.Africa	254557	242261	1.01	3.78	0.74	0.42	0.32
S.Africa	60577	168166	2.84	3.86	0.51	0.09	0.42
W.Africa	613344	433789	0.79	1.15	0.42	0.98	-0.56
N.America	392978	482517	1.27	7.07	3.02	0.54	2.48
C.America	180108	127395	0.74	3.56	0.39	0.29	0.10
Caribbean	47144	12706	0.28	1.90	0.02	0.09	-0.07
S.America	460777	581274	1.32	5.11	2.48	0.6	1.88
E.Asia	1653595	696411	0.43	6.73	3.82	2.78	1.04
S.C.Asia	2145999	592677	0.29	4.56	2.46	3.35	-0.89
S.E.Asia	686251	115010	0.17	5.17	0.58	1.14	-0.56
W.Asia	293144	270874	0.99	3.74	0.82	0.47	0.35
Europe	715220	478061	0.66	5.92	2.66	1.04	1.62
Oceania	41421	464734	11.77	2.94	1.09	0.01	1.08
World	8010509	4967578	0.65	4.70	19.46	12.55	6.91

4.3 Comparison of potential productions of food and biofuel with other studies

The maximum potential food production indicated in this study is far less than the potential shown by Penning de Vries (1995) and Wolf *et al.* (2003) which was estimated to be 31 and 19 Gt per annum respectively with the LEI production system. Penning estimated with the consideration of the global potentially suitable agricultural land for mechanized farming, and Wolf focused only on the present available agricultural land (5 billion hectares). Therefore, the result of this study with the highest scenario (19.5 gt per annum) is consistent with the study by Wolf *et al.* (2003).

For the sake of comparison, only the highest scenario from this study was considered.We came across a few studies on the estimation of global potential liquid biofuel production from energy crops with respect to regional production. However, it was tried to compare with results shown by Wolf *et al.* (2003) and Smeets *et al*.(2007). The global potentially available agricultural land for biofuel production was compared with the Wolf et al.(2003) estimation. Thus, the estimated amount of land in this study (2.3 Gha) is in line with theWolf et al.(2003) estimation (2.25 Gha). The global potential energy production was also compared. Smeets *et al*. (2007) estimated 1190 EJ of energy using potentially suitable surplus agricultural lands. And the result of this study (0.9 EJ) is far less than this estimation due to the variation in crops yield used in both studies. The crop yield used in the Smeets *et al*. (2007) study was 4 times more than the average yield used in this study.

4.4 Potential contribution of biofuel to future energy demand

The maximum potential production of biofuel estimated according to this study is 0.9 EJ of energy. However, the Energy Information Adminstration (EIA) reported 651 quadrillion Btu which is equivalent to 700 EJ total global energy demand at 2025 (International energy outlook, 2008).Out of this, total global oil demand constitutes 30% (200 EJ). Accordingly, the estimated potential energy production according to this study only contributes 0.14% of the global total energy demand or 0.5% of the tatal global oil demand projected for this year. Different contrasting factors are also considered to decide its extent of contribution along with its quantity. Accordingly, the amount of energy consumed from crop cultivation to final biofuel production also accounted as one of the main contrasting factors from its life cycle analysis. Even though, the amount of energy consumed in the process of production depends on the system of production and energy crops exploited, some energy crops consume high amount of fossil fuel to biofuel output ratios (Blottnitz *et al*., 2007). Another study also indicates high emission of SO_2, NO_2 and CO_2 from biofuel cycle than fossil fuel. Most of this emmision sources are from combusition of fossil fuel for fertilizer production, transportation and on biofuel conversion processes (MacLean *et al.*, 2000). Environmental pollution from intensive farming is also another short coming of the biofuel production indicated. In conclusion, with the consideration of these constraints, the contribution of biofuel as a renewable substitute is deemed to be insignificant.

4.5 Significance of biofuel production from degraded land

Biofuel production was estimated from tropical and sub-tropical degraded lands. The most easily adaptable energy crop (Jatropha) to harsh climatic and such soil type was used. Jatropha is a small tree or tall bush (up to 5 meters in height) which grows abundantly in tropical and sub-tropical regions. It has a seed production lifespan of 50 years, is a fast-growing, drought-resistant perennial producing seeds with oil content of about 37% (Katembo et al., 2007). This tree, before it was known as energy crop, was used as erosion protection and fences in many parts of tropical regions. The resources used as an input for its production are relatively very minimal. Other energy crops need intensification and consume high amounts of fossil fuel from crop growing to fuel processing. Jatropha can be regarded as a promising inedible energy crop for rural people in developing countries especially in sub-Saharan regions as an income earning, satisfying domestic energy consumption with minimum input, and as a restoration of highly degraded lands in the regions. This is briefly shown in a study conducted by Mangoyana (2008).

CHAPTER 5: CONCLUSION

Despite the shortage of food in some regions of the world, potentially surplus agricultural land was available in other regions with the initially high yield, large surface area to population ratio and low population growth rate. Accordingly, North American, South American, European and Oceanian regions are regions with potentially high available surplus agricultural lands. However, with respect to global potential, no biofuel production is possible with the present production situation if every person around the world demands a moderate diet. To investigate the possibility of biofuel production in the future (2025) with maximum production scenario expansion of arable land, shifting of meat production system and doubling of the present yield was devised. Accordingly, with these maximum resources exploitation 0.9 EJ of energy at global level was estimated, and its contribution as a renewable energy sources was analysed. Therefore, the lifecycle analysis of the fuel and comparison to the global total energy demand was undertaken. Hence, it can only contribute 0.14% of the 2025 total global energy demands (International energy outlook 2008). In addition, with the consideration of fossil fuel consumption for intensification of farming and fuel production process, its substitutability to fossil fuel is not very significant. Furthermore, subsequent environmental pollution was also concerned. Therefore, in conclusion, with all these consideration, production of biofuel from energy crops using surplus agricultural land is not very promising.

However, the production of biodiesel from Jatropha on tropical degraded land is found to be a promising energy crop for poor tropical farmers. The production of this energy crop is unlike that of other energy crops. It needs little or no external input like fertilizer. Farmers can easily grow and use as a source of income. Furthermore, it easily reduces the external energy dependency of these poor regions to a certain degree. Therefore, it might be one of the income earning sectors to reduce poverty. Beyond these, it can also serves as a way of reducing soil erosion and restoration of degraded lands.

CHAPTER 6: LITERATURES

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