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Possibility of food and biofuel production in developing countries

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Abstract

The production of biofuel has gotten considerable attention around the world including developing countries despite a lot uncertainty. Many attempts have been made to determine the possibility of biofuel production at different regions of the world. These studies have shortcomings in that the present situation rarely had not been considered. Therefore, it is necessary to develop methodology provides better estimates of both commodities (food and biofuel) taking into account the present level of yield and food demand. Hence, the current paper aims to provide better estimates up to the year 2025 based on the present size of cultivated land, level of yield and demand for food. Three different scenarios with three different diets were considered for the estimation of both commodities, but moderate diet against scenario 3 (S3) of production were considered in light with food security criteria production-demand ratio of 2. Food production converted to grain equivalent to incorporate the different composition of human diet. Estimation has been made to determine global possibility in general and then for developing countries in particular. In light with the above considerations, biofuel production from surplus agricultural land only satisfies 0.14% of the 2025 total global energy demands whereas the possibility in developing regions are overshadowed by growing population and food demands.

Key words: surplus land, food production, food demand, biofuel production, grain equivalent

1. Introduction

The term biofuel refers to the form of energy extracted from biomass sources, however, in current paper it refers to the first generation liquid biofuel derived in the form of bio ethanol and biodiesel. Recently, biofuel has been given world wide acceptance as viable alternatives to fossil fuels. The large scale production of biofuel from sugar cane and sugar beet began in the early 1970's in Brazil and United States of America. Since then, other countries such as European countries engaged in biofuel production. At present biodiesel from *Jatropha curcas* is produced in India and other tropical countries [1-3]. As with any technical innovation, biofuel production has some perceived negative impacts although it is considered to be a good opportunity for developing countries having large surface area of land which can have the opportunity to produce and export in a competitive market [4]. This shift in crop preference is considered as one of the inducing causes of the soaring food price and reduction in food production [5-7].

Many studies have been done to determine the uncertainties of future food production from suitable agricultural lands. Estimates have shown that, assuming application of the best technology, abundant food supply could be available in the coming decades [8-9], ample biofuel production had also been projected for 2050 [10-11]. These studies have shortcomings in that the present situation rarely had not been considered. A varying contrary prediction was also indicated emphasizing on the environment and food security [4, 6]. The variations between these estimations may be due to the difference in the protocols used [12]. Therefore, it is necessary to develop a methodology that can provide better estimates of both commodities (food and biofuel) taking into account the present level of yield and demand. Hence, it aims to estimates the possibility of biofuel production in developing countries up to the year 2025 based on the present size of cultivated land, level of yield and demand for food.

2. System structure

The current paper systematically organized and framed in the way it provides plausible estimates of the possibility of food and biofuel production in developing countries (Fig.1). Developing countries refer to regions involving countries in the least developing economy of World Bank category. The incorporated information was obtained from different databases. UN population division and FAOSTAT databases used to retrieve data regarding population growth, land resources, food production and consumption. Additional data on grass land production and productivity, biofuel yield and conversion was supplemented from literatures. Lastly, a simple scenario model was developed in light of this information by integrating different food demands, crop yields and land use. The residue from food demand was considered for biofuel production. Other data from all regions of the world were incorporated for the sake of comparison.

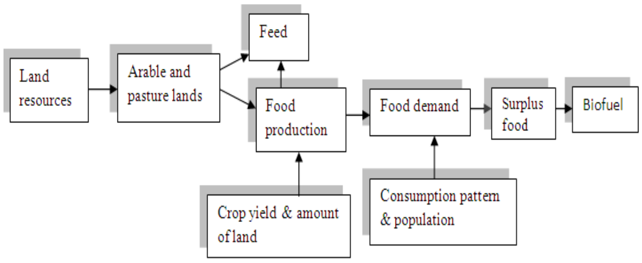

Figure 1 Schematic representation of system structure

2.1 Global population and land division

The global land area and corresponding population were divided into 14 regions in accordance with United Nation population division (1992) [13]. Although regions differ in many aspects including agro-ecological conditions and socio-economic status; those having relatively similar character were merged to adjust with other available data sources. For example, Northern Europe, Southern Europe, Eastern Europe and Western Europe were regarded as one region. Population and food production for the year 2010 and their projection to 2025 were considered as the present and future population and food production respectively. Available agricultural lands (arable land and pasture land) were exclusively allocated for the production of both (food and biofuel) commodities by excluding other land categories like forest and marginal lands.

2.2 Global food production

The 2025 global food and biofuel production were estimated under three scenarios, namely scenario 1 (S1), scenario 2 (S2) and scenario 3 (S3). Scenario 1 is characterized as lowest production system without any change to the present agricultural land, pasture land and crop yields. S1 was modelled exclusively using arable land for crop and pasture land for red meat (i.e. beef and mutton) production at 2010 annual yield level. It was assumed to be the lowest scenario due to the fact that, all the model inputs were the present minimum land resource and crop yields. This S1 is modelled with present 1.6 billion hectares of arable land and 3.4 billion hectares of pasture land with usual trend projection of the present yield and population. The usual trend yield projection data for each region was taken from Bruinsma (2003) [14]. An average of five years (2006-2010) yields of the most commonly grown crop of the regions from FAOSTAT was projected to 2025. A Crop that covers more than 50% of the harvested land of the region was assumed to be most commonly grown crops, and therefore, extrapolated to the regions' total cereal production. The meat production for this scenario was estimated only from pasture lands in pastoral production system in accordance with the amount of pasture land production and productivities. The variation could be due to the extent to which the grass converted to a certain animal products depends on the type of grass, conversion efficiency and yield of the grass. The regional pasture land production data provided by Bouwman 2005 [15] were used for the estimation. The regional grass yield per hectare was calculated from the regional available pasture land and estimated amounts of grasses. Subsequently, the amount of grasses produced from regional pasture lands were converted to meat and milk according to the specific conversion factors for each region [15].

S2 was developed between minimum and maximum production by expanding the present arable land by 75% to pasture land. Currently, the largest available global agricultural land (3.4 billion hectares) is allocated to the production of red meat. This kind of production system is assumed to be inefficient, that relatively more land is needed to produce a kilogram of meat. In order to satisfy the increasing food demand of the growing population, it is necessary to consider alternative meat production. Shifting the type of meat production particularly from red meat might be a better option. However, the shifting also needs change in production system that relies on food crops. Therefore, 75% of the pasture land was converted to arable land while the remaining 25% was allocated to milk production, albeit it was deemed not enough to satisfy the required milk demand. The conversion of the pasture land would increase the present global arable land to the maximum of 4.12 billion hectares. The yield level for cereal crops and milk production was the same with that of S1. The remaining milk demand for moderate diet was calculated from food crops to satisfy the required dietary demands. The allocation of meat production to the categorical diet was carried out depending on the share in the diet and higher energy value of the type of meat [8]. The energy value supplied with pork is thrice that of poultry and the share in moderate diet is also 10:1. In order to meet the requirements, the large portion (75%) of the meat production was allocated to pork and the rest to poultry. Eventually, the total food demand and land requirement was extrapolated from the per capita per year diet.

S3 is the maximum scenario wherein 75% of the present pasture land was converted to arable land with doubling of the present crop yield. Increasing the yield is another possibility of increasing production. This can be attained either by using irrigation or an intensive farming system or both. A study showed that variation of the cereal yield ranges from less than 1 tonne to more than 7 tonnes per hectare in different regions of the world [16-19]. The production potential is high particularly in tropical regions where there is the possibility of producing crops more than two times per year [8-9]. Therefore, doubling of the present cereal yields to a maximum of seven tonnes per hectare was assumed to be practical with a certain input. Doubling of the yield for the projected year was estimated with the annual increase rate of 4.7%. Seven tonnes per hectare was taken as a maximum production, due to the fact that the production potential in North American regions was seemingly saturated [14] unless crop biotechnology advances.

2.3 Conversion to grain equivalent (GE)

The different composition of food items were incorporated into estimation by converting to grain equivalents. Grain equivalent (GE) is a hypothetical weight unit which was frequently used in the estimation of food production and consumption with varied operational definitions. Wolf *et al*., (2003) [10] defined GE as a dry matter of a certain food items used as a raw material for a certain products, i.e. plant, diary and meat products. For the sake of convenience, we adopted this definition and the values of conversion factors developed by Luyten (1995) [8] for the whole calculations (Table 1).

Table 1 Dietary composition of moderate diet and conversion factors to Grain equivalent

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
Powder milk	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
Total	1626	6178	10046	5.0	81.2	1.45	2355

Source: [8]

2.4 Estimation of food demand and surplus agricultural land

Food demand was calculated from the total population and per capita food consumption. Data for per capita per day for different diets was taken from Luyten (1995) [8] in grain equivalent. However, the per capita food consumption varies with food consumption pattern, and categorized as vegetarian, moderate and affluent diets. The moderate diet assumed to be representative to fulfil the basic caloric requirements. The minimum caloric intake and daily protein requirement for an adult person is estimated to be 10MJ and 1.0 g per kg body weight respectively. The basic caloric intake of all diets is the same except with an increasing animal protein contents in affluent diets than a vegetarian diet [8].

All the food items included in each diet category were converted to grain equivalent as per their specific conversion factor. Those conversion factors were the weighted averages of the conversion factors of the various food items included in each category of the diet (Table 2). The amount of grain required for each diet varies significantly, and therefore, affluent diet requires four times than that of vegetarian diet. An adult person requires 1.3, 2.4 and 4.2 kg GE per day for vegetarian, moderate and affluent diets respectively. The basic caloric intake in both vegetarian and moderate diets was almost similar [10 MJd^{-1}] with minor variation in affluent diet [11.5 MJd^{-1}]. Significant variation occurs in the kind of protein sources taken in food. The source of protein in a vegetarian diet is mostly from plants whereas in moderate and affluent diets, it is from plant and animal origin. The net protein intake does not show great variation, but significant variations exist in the grain needed to produce the animal protein. Affluent diet needs high amount of grain to produce the amount of animal product in the diet.

Table 2 The basic dietary requirement for vegetarian, moderate and affluent diets

Diets	Consumption [gd^{-1}]	Energy intake[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

Source: [8]

Moderate diet was considered in the estimation of surplus agricultural land, since it can fulfil the basic dietary requirements from plants and animal products. The surplus agricultural land was extrapolated from the estimated surplus foods. The surplus food was calculated from the production demand ratio of 2 [10]. Doubling of the demand was to overcome the expected shortage of food due to yearly production variation and loss on transportation. Biofuel production was estimated from resulting surplus agricultural land.

2.5 Estimation of biofuel production from surplus agricultural land

Bio-fuels are a wide range of fuels which are derived in some way from biomass. For this study the only liquid bio-fuels that can be extracted from agriculture in the form of bio-ethanol and biodiesel were considered. Its production was estimated from crops with high energy contents and yields. Bio-ethanol production was estimated from sugar beet and sugar cane whereas biodiesel, from Rapeseed and Jatropha. The potential production was estimated from the sugar content of each energy crop converted to bio-ethanol or from oil content to biodiesel (Table 3). Energy crops' yield data was taken from FAOSTAT except that of Jatropha taken from [20-23].

3. Results and discussion

3.1 Global food production and demand

The global potential food production with S1 was estimated at 6.73 Giga tons of grain equivalents. This estimate cannot satisfy the amount of food required with moderate diet (Fig.2). The study indicates remarkable increase in food production in S2 due to shift of meat production systems. It is indicative that production of red meat is relatively inefficient compared to that of white meat (i.e. Pork and Poultry). Hence, the total production in S2 was estimated to be double compared to that of S1 (Table 4).

Table 3 Energy crops yield and its conversion values to biofuel

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	”

***calculated from % of oil content*

Source: [16, 19, 21, 23]

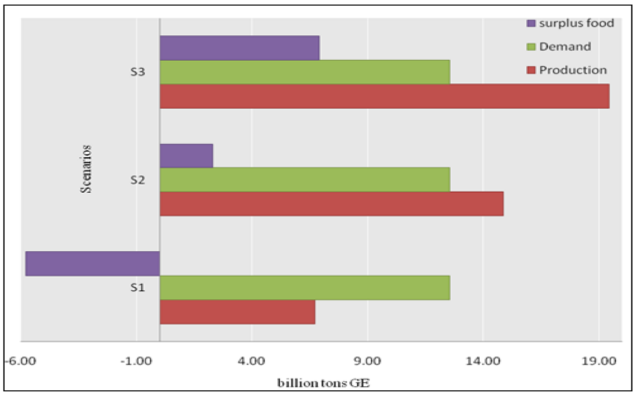

Figure -2: Global food production potential, demand and surplus food at 2025

Table 4 Global food production potential and demand in various regions of the world in 2025

Regions	Total 2025 population [1000]	Scenarios of food production [Gt GE per year]			Food demand [Gt GE per year]		
		S1	S2	S3	vegetarian	moderate	affluent
Eastern Africa	465394	0.10	0.34	0.44	0.34	0.73	1.28
Northern Africa	254557	0.13	0.51	0.74	0.20	0.42	0.72
Southern Africa	60577	0.06	0.39	0.51	0.04	0.09	0.17
Western Africa	613344	0.12	0.32	0.42	0.46	0.98	1.71
Northern America	392978	1.71	3.02	3.02	0.21	0.54	1.01
Central America	180108	0.12	0.27	0.39	0.12	0.29	0.70
Caribbean	47144	0.01	0.02	0.02	0.04	0.09	0.27
Southern America	460777	0.58	1.73	2.48	0.21	0.60	1.14
Eastern Asia	1653595	0.99	3.16	3.82	1.38	2.78	4.73
South-Central Asia	2145999	1.12	1.83	2.46	1.53	3.35	5.88
South-Eastern Asia	686251	0.35	0.40	0.58	0.56	1.14	1.95
Western 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

The overall result for S2 and S3 indicated great potential regional production variations. The regional variation is attributed to the differences in amount of pasture land and crops yields. High shortage of food was observed in regions with the initially lower yield, high population growth rate and lower per capita agricultural land area. East Africa, West Africa and Caribbean are regions, already with lower present yield and high population growth rate, expected to experience high shortage of food with moderate diet. In these regions, the initial present yield was less than 1 tons per hectare per year (FAOSTAT) with a population growth rate of 2.4 percent per year (UN population division database). Doubling of the present yield and expansion of arable land would not contribute significant change to food self sufficiency. Similar shortage was observed in South-central and south-eastern Asian regions. South-Central Asia feeds approximately 25% of the world population with 0.29 hectare agricultural land per person whereas South-Eastern Asia provide with 0.17 hectare agricultural land per person. On the contrary, the highest production potential was observed in Eastern Asia, North America and Oceania regions. The higher production was attributed to the high level of regional crop yield and amount of existing pasture land. Doubling the present yield in S3 resulted in an estimated potential production of 19.46 Giga tons grain equivalents (Table 4). This estimated amount can satisfy the demand for moderate diet with residual food crops for biofuel production. The estimated production in the current study is by far less than the estimation made by Penning de Vries (1995) and Hoogwijk *et al*. (2005) [9, 24]. These authors had estimated 72 and 35.6 Giga tons grain equivalent respectively. The difference between these estimations was due to the fact that, their estimation depended on the land suitability for modern farming and was not based on the present regional yields. Only arable and pasture lands were considered in the current study excluding the other land resources. Beside to that, a maximum of seven tonnes per hectare was assumed as a ceiling yield, but in their estimation they estimated 16-20 tons per hectare for tropical irrigated lands.

3.2 Global bio-fuels production potential

The global food demand in the three scenarios was analysed 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 in Fig.2. It was found that no global surplus agricultural land is available with affluent diet in all scenarios. With S1, no surplus land is available with any of the three diets. The availability of biofuel production needs extra input that can increase production to satisfy the increasing food demand [10]. With S2 and S3 2.31 and 6.9 Giga tons of grain equivalents of foods were estimated to be available for bio-fuels production. The maximum estimated surplus land in S3 was converted to 2.3 Giga hectares of surplus agricultural land. The estimated surplus land (2.3 Giga hectares) was in accordance with Wolf *et al.* (2003) estimation (2.25 Giga hectares). It is possible to produce the maximum of 0.9 EJ (Exajoule) of energy per annum from bio ethanol and 0.2 EJ of energy per annum from biodiesel global level (Table 3). The current estimate is significantly different from the Smeets *et al*. (2007) [11] estimation of 1190 EJ of energy per annum, and can be attributed to variation in crops yield used in both studies. The yield of crops used in the latter study was 4 times more than the maximum yield used in current study. With S1, production of biofuel is unlikely. The estimated energy production potential contribution to future energy demand was analysed in comparison with global total energy demands. The Energy Information Administration (EIA) [25] reported 651 quadrillion Btu (700 EJ) of total global energy demand for 2025 (International energy outlook 2008), out of which oil demand constitutes 30% (200 EJ). The current estimation only contributes 0.14% of the global total projected energy demand or 0.5% of the total global oil demand. The current estimation was regardless of the energy consumed and the amount of polluting gases emitted in the processes of production that could be considered for its substitutability for fossil fuel.

3.3 Trade-off between food and biofuel production

Energy is vital to modern economic and welfare development. However, the current fossil fuel is alarmingly polluting, scarce and surging in price that poor developing countries unable to afford [6]. Biofuel could be a possible option of substitute despite the recently growing concern with food security. Despite this issue there is a growing interest of biofuel production both from developed and developing countries including such countries relying on food aids [26]. It was also evident with the current study that there is a potential possibility for bio-fuels, but needs to develop strategies that can create trade-off between food supply and biofuel. Advancement of agricultural biotechnology, shift in food consumption pattern, linking agro-economy to industrial economy enabling to encourage small scale farmers. Ruane, Sonnino, & Agostini (2010) [27] emphasized the importance biotechnology in developing countries to promoting biofuel. Change in diet pattern and yield is also very crucial [28].

Those regions without surplus agricultural lands are experiencing lower crop yield with large surface area to population ratio are residing in tropic and sub-tropics. They are endowed with substantial alternative energy resources possibly provide modern energy supply. Most importantly, large marginal lands available in the regions can open additional an window of opportunity for biofuel production from non-edible crops. Biofuel based energy therefore can be made available to satisfy basic energy needs particularly for those import oil dependent countries. Hence small scale family based production of energy crops like jatropha could possibly provide a double advantage as a means of income for poverty alleviation and energy crop production [29-30]. Despite its paramount impact, biofule production can provide substantial socio-economic benefits [31]. However, integrated policy focusing on small scale production, environmental awareness and creation of market opportunities needs to be developed and must be in place.

3. Conclusion

Despite the shortage of food in some regions of the world, there are also potentially available agricultural lands in such regions with high crop yields, large surface area to population ratio and low population growth rate. North American, South American, European and Oceanian regions are regions with potentially high available surplus agricultural lands for biofuels production. The remaining regions of the world do not have promising potential of biofuel production from surplus agricultural lands, but there can be a pocket of opportunity if agricultural biotechnology, small scale and agro-forestry from range land with good policy will be considered. Because, the possibility of having surplus land for biofuel production relies on the expansion of arable land, shifting of meat production system and doubling of the present yield.

Therefore, the possibility of biofuel production in developing countries needs to have an integrated policy approach comprising of environment, socio-economic and creation of supply-
demand markets.

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