Analysis of the Base Material Footprint of Conventional and Lignocellulosic Biofuel Production

D Szalay¹, V Papp², and I Czupy³

¹PhD candidate, MSc Energy management engineer, University of Sopron, Sopron, HU
²PhD candidate, MSc Environment researcher, University of Sopron, Sopron, HU
³Associate Professor, Head of Institute of Forest and Environm. Techniq. University of Sopron, HU
E-mail: szalay.dora@uni-sopron.hu

Abstract. The base material footprint (BMF) is a measuring system that provides the theoretical collection area for a unit of biofuel base material. Eight different types of base materials of three countries were examined; four types of biofuel had been taken into account. According to the results, the collection area varied between 0.08 -0.61 ha to produce 10 GJ biofuels. It required the smallest collection area the forest residues, while the largest had the corn stalk. The change of the collection area due to yield fluctuations in the last decade, was the largest in the case of corn and corn stalk for bioethanol, over 70% in a very droughty year. Further comparison was performed for the theoretical and real collection areas for corn. Under real conditions the collection of base materials needs 10 times bigger area. This can increase up to 20 due to utilization for animal feed and green manure.

1. Introduction

The global energy consumption has stagnated in the last two years, achieving the goals of COP 21 (Paris 2015) is far behind. Today, the most important energy source is petroleum. Its use in the transport sector is continuously increasing, covering 32% of global energy use in 2016 [1]. Long-term use of fossil fuels raises serious questions such as global warming and the depletion of fossil fuels. A more significant problem is that the resource of conventional hydrocarbons is locally concentrated; the market is mostly dominated by the Middle Eastern countries. The energy vulnerability of other countries can lead to geopolitical disputes.

Primary and secondary lignocellulosic energy sources will have significant importance in reducing energy dependence and in restraining of climate change. In 2016, 11% of the world's energy consumption was covered by biomass [1]. Within this, the use of biofuels in the road transport sector was 3.5% [2]. The use of cereals and oilseeds is rapidly expanding. While a hundred years ago corn and sunflower were only considered as a food plant, they are important sources of biofuels today. The most important task is to involve non-food by-products of agricultural, of forestry, of industry and of household into biofuel production. Due to the technological development in recent years, a wider range of base materials is available for the production of biofuels, see Figure 1.

The conversion of applied new lignocellulose base materials into biofuels requires a much more complex technology than the first-generation biofuel production. At present, the production of advanced fuels is not costeffective because there are a number of technical barriers that need to be overcome before their potential can be realized [3]. However, the second generation biofuels may be more advantageous for land use demand.
According to Sanderson’s (2006) research, the bioethanol yield of Miscanthus is the highest, with a maximum of 7,300 l/ha. The lowest in the case of corn 3,100-4,000 l/ha. Utilization of by-products will result in further improvement [4]. Currently, 6,000-7,000 l of ethanol is produced from one hectare of sugarcane. When bagasse, thatched, straw can also be utilized for ethanol production, the output is likely to double to 12,000-15,000 l per hectare [5,6].

In case of biodiesel, the intake of waste cooking oil (WCO) to production may improve the amount of base material collection area. WCO has great potential worldwide, about 70% of the WCO would be recoverable in the cities [7]. Another advantage is that they can be added into existing plants without their conversion. In Vietnam, fish fat has significant potential, in addition to WCO. The waste of catfish is 120,000 t/year. However, the cost of biodiesel from fatty fish is still higher than diesel due to the higher price of fish oil [8].

2. Legal Background

In the future, the European Union (EU) wants to limit the food crops for energy production. On 6 April 2009, the European Council (EC) adopted the EU Energy and Climate Package (2009/28/EC), which provides 20% renewable share in total energy consumption for the EU as a whole. A further objective is 10% share of renewable energy by 2020 in the total energy use of transport, binding for all EU Member States. The 2015/1513 Directive (iLUC) represents a major tightening of the previous standards, limits the share of biofuels from crops grown on agricultural land that can be counted towards the 2020 renewable energy targets to 7%.

In Vietnam there are two important requirements for the use of biomass. The main objectives of the national energy development strategy up to 2020, with 2050 vision (Decision No 1855/QĐ-TTg; December 27, 2007) to increase the proportion of new and renewable energies to about 5% of the total amount of commercial primary energy by 2020 and 11% by 2050. The goals of the National program

Figure 1. Expanding the choice of base materials to advanced biofuels.
for development biofuels up to 2015, with 2025 vision (Decision No 177/2007/QD-TTg on November 20, 2007) to develop biofuel, a new and renewable energy, for use as an alternative to partially replace conventional fossil fuels, contributing to assuring energy security and environmental protection. The biofuel production technology applied in Vietnam will attain the world's advanced level. The ethanol and vegetable oil output will reach 1.8 million tons, satisfying some 5% of the whole country's gasoline and oil demand. In Vietnam, the Ministry of Industry and Trade is not extending the January 1, 2018 deadline for petrol wholesalers to switch to E5 biofuel made from cassava.

3. Materials and Methods
During the calculation of BMF, we conducted a complex analysis. Our focus was on Europe and Vietnam, where the used materials are extremely diverse due to the climatic and ecological conditions, but there are serious parallels in the problem of supply.

3.1. Selection of examined base materials and yield analysis
Three countries were analyzed and compared. The typical characteristics for the production area of the selected countries are shown in Table 1.

|                  | Forest area (%) | Agric. area (%) | Arable land (%) | Arable land (10^6 ha) |
|------------------|-----------------|-----------------|-----------------|-----------------------|
| Germany          | 33              | 48              | 34              | 11.9                  |
| Vietnam          | 48              | 35              | 21              | 6.4                   |
| Hungary          | 21              | 57              | 46              | 4.3                   |

Our investigation was performed on four types of biofuels, four main agricultural products and three high-lignocellulose containing by-product, see Table 2. Depending on the availability of the data [11,12], the median value of the yield of the base materials was calculated considering the last 7 or 10 years in order to dampen the outlier values and determine a more realistic yield. The amount of corn stalks and rice straw was calculated by using the crop:stalk/straw ratio. According to the literature, crop:stalk ratio is 0.8-1.5 in the case of corn, and 0.7-1.4 in the case of rice [13, 14, 15, 16]. Currently, the utilization of corn stalk approx. 93-94% of the sown area is the plowing in to the soil. [17]. Approximately 80-90% of the rice straw is disposed by open-field burning; however, in some periods of the year, rice straw has a market for cattle feed and mushroom cultivation [18].

| Type of biofuel | Applied technology | Type of base material | Yield (t/ha/year) |
|-----------------|--------------------|-----------------------|-------------------|
| 1st gen bioethanol\(a\) | fermentation of plants containing sugar and starch | corn (Germany) | 9.70 |
|                  |                    | corn (Hungary)       | 6.43              |
|                  |                    | corn (Vietnam)       | 4.31              |
|                  |                    | cassava (Vietnam)    | 17.68             |
| 1st gen biodiesel\(b\) | transesterification of vegetable oils and animal fats | rapeseed (Germany) | 3.90 |
|                  |                    | rapeseed (Hungary)   | 2.67              |
|                  |                    | soya-bean (Vietnam)  | 14.50             |
| 2nd gen bioethanol\(a\) and biodiesel\(bc\) | enzymatic hydrolysis and pyrolysis of cellulose | corn stalk (Germany) | 3.88 |
|                  |                    | corn stalk (Hungary) | 2.57              |
|                  |                    | rice straw (Vietnam) | 4.84              |
|                  |                    | forest residues (Hungary) | 9.88 |

\(a\)median 2007-2016
3.2. Base material footprint for theoretical and real area

The basic idea of a BMF system is the well-known ecological footprint. The ecological footprint is the only metric that measures how much nature we have and how much nature we use. The lower the ecological footprint, the more consistent it is with the use of available natural resources. The BMF gives the theoretical collection area of unit of biofuel. It was determined for 1 ton of biofuel weight. Due to the different energy content of biofuels, 10 GJ of energy was determined, as well, for better comparability. In case of corn, the data on theoretical areas were extended to a real environment. Our investigations were carried out in the area of 50 km radius of two intensively utilized agricultural district in Hungary. The coordinates of the center of the districts are 47°31’64.4”N, 18°90’84.7”E and 47°54’57.5”N, 21°2’33.8” E

4. Result and Discussion

The yield of the main bioethanol and biodiesel base materials in EU shows a high fluctuation compared to Vietnam, due to the different climatic conditions. Among the analyzed biodiesel base materials, the highest yield loss (-25%) was shown by rapeseed production in 2011 in Germany comparing to the median value. In Hungary, the yield of rapeseed remained below 20% of the average in 2010 and significantly exceeded the average yield in 2014 and 2016. The yield of soybean in Vietnam was quite balanced, the maximal yield loss did not reach 2% (2014), while the highest yield was experienced in 2016 (+8%), see Figure 2.

![Figure 2. Yield fluctuation of the examined base material of biodiesel between 2010-2016.](image)

The yield fluctuations of corn were particularly problematic in Hungary. It has almost disappeared by 40% of the mean value (2007, 2012, 2016), see Figure 3. This had serious consequences in the production of biofuels. In Hungary, about 20 bioethanol producer plants were under construction or authorization procedure from 2006, but none of them was successful due to the extremely low corn harvest in 2007. The reason in most cases was the strong increase in the price of base materials and the lack of continuous feedstock. In Vietnam, none of the two examined base materials exceeded 10% yield fluctuations. In Vietnam, the main problem was the lack of a domestic biofuel market and the
high base material price, which made the exports of biofuel even more difficult. Because of the multiple use, there were not enough raw materials for biofuel production, even though it was located near a cassava cultivation area. Because of the limited area and manual cultivation, cassava prices have remained very high [19, 20].

Based on our research, the lowest BMF is available in the production of biooil from forest residues, see Table 3. Although the technology is in the research phase, some plants already operate in commercial scale. In Hengelo in the biooil plant a number of raw material was tested and wood residues gave the most favourable biooil yield [21]. With regard to the main agricultural products, soybean-based biodiesel has given the most optimal area. Although its oil content is much lower (~18%) [22, 23] than the rapeseed (~40%), [24] it requires a much smaller collection area, due to more than four times yield per hectare. Among the agricultural by-products, rice straw can be collected from the smallest area to produce a unit of biofuels due to high lignocellulose content and high yield per hectare. In Vietnam, rice straw has great potential, currently used only to a small extent for animal feed and other purposes. The corn stalk has the highest base material footprint. However, they also represent a large untapped potential.

![Yield fluctuation of the examined base material of bioethanol in the last 10 years.](image)

**Figure 3.** Yield fluctuation of the examined base material of bioethanol in the last 10 years.

| Table 3: Base material footprint for 1t and 10 GJ biofuel |
|-----------------|-----------------|-----------------|-----------------|
| Type of biofuel | Type of base material | BMF for 1t biofuel [ha] | BMF for 10 GJ biofuel [ha] |
| **1st gen bioethanol** | corn (Germany) | 0.34 | 0.13 |
| | corn (Hungary) | 0.51 | 0.19 |
| | corn (Vietnam) | 0.76 | 0.28 |
| | cassava (Vietnam) | 0.61 | 0.23 |
| **1st gen biodiesel** | rapeseed (Germany) | 0.61 | 0.16 |
| | rapeseed (Hungary) | 0.89 | 0.24 |
| | Soya-bean (Vietnam) | 0.37 | 0.10 |
| **2nd gen bioethanol** | corn stalk (Germany) | 1.08 | 0.40 |
| | corn stalk (Hungary) | 1.63 | 0.61 |
| | rice straw (Vietnam) | 0.83 | 0.31 |
| **2nd gen biooil** | corn stalk (Germany) | 0.59 | 0.34 |
| | corn stalk (Hungary) | 0.89 | 0.51 |
| | rice straw (Vietnam) | 0.50 | 0.29 |
| | forest residues (Hungary) | 0.14 | 0.08 |
From the security point of view of the base material supply, the corn and corn stalk are the most unfavourable source of biofuels, see Figure 4. The increase of BMF can exceed 72% due to yield loss in drought years in Hungary. In the case of forest residues, yield fluctuations are not relevant; however, availability of base material depends on the actual forest logging plan. Collecting them can be cumbersome and ecological problems caused by contagion and organic matter removal. However, the intensified use of first generation biofuel could endanger the worlds agricultural areas because of the increasing use of pesticides and artificial fertilizers on industrial produced monocultures [25].

![Figure 4. Change of base material footprint depending on the yield.](image)

In the case of corn, we were investigating that how much larger area the real base material footprint covers, compared to theoretical base material footprint. We selected two areas in Hungary where intensive farming is taking place. As biomass can be transported within a max. 50 km radius [26], therefore, we have taken such a large area. The result is that the collection of the same amount of corn or corn stalk in real conditions requires 9 to 11 times bigger area. If we are taking into account the impact of drought, the required area will rise to 20 times bigger. In case of corn stalk, the BMF in real condition is more than 7 times bigger in the case of second generation biooil, and 15 times bigger if we count with the technical loss, and the need of the green fertilizer demand, and animal husbandry.

5. Conclusion
The importance of the develop of methods of base material footprint system is to facilitate the correct selection of the biofuel type and the production technology that is compatible with the available base material in the area. Improperly funded investments have serious consequences. Many bioethanol plants have not been realized or closed over the past 10 years regardless of geographical location, thanks to high raw material prices due to various reasons. The choice of biofuel base materials has undergone a strong transformation over the last decade. The range of base materials that are less endangered for the food supply security is expanded, but still sustainable. To develop a base material footprint system, all applicable base materials would be under investigation in different geographic environments. It should also be taken into account that more than one raw material can be included in the biofuel production system at the same time. The lower is the base material footprint of the biofuel, the smaller the collection area and the required transport distance are. According to our research, forest residues have the lowest area requirement. However, collecting them is cumbersome and a considerable by-product only occurs in case of clear cutting. Most of the by-products are concentrated in the wood processing industry, but they are still largely utilized today. Agricultural by-products, i.e. corn stalks, rice straws have a high potential, however, because of their low bulk density, transportation is not economical for long distances, and
their conversion rate is low. At the same time the risk of iLUC can be reduced. During the planning of the biofuels plant, the effect of extreme weather must be taken into account, which can increase the collection area by up to 70%. Meeting the ecological needs doubles the base material footprint. The agricultural by-product is also used in animal husbandry. Harvesting and storing corn stalks with high moisture content is still cumbersome.

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Acknowledgement
The described work was carried out as part of the „Sustainable Raw Material Management Thematic Network – RING 2017”, EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.