Sustainability aspects of biofuel production

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Abstract. Nowadays, world development depends on the energy supply. The use of fossil fuels leads to two threats: depletion of resources within a single century and climate changes caused by the emission of CO₂ from fossil fuels combustion. Widespread application of renewable energy sources, in which biofuels play a major role, is proposed as a counter-measure. The paper made an attempt to evaluate to what extent biofuels meet the criteria of sustainable development. It was shown that excessive development of biofuels may threaten the sustainable development paradigms both in the aspect of: intergenerational equity, leading to an increase of food prices, as well as intergenerational equity, resulting in degradation of the environment. The paper presents the possibility of sustainable biofuels production increase.

1. Introduction

The idea of sustainable development was created by Brundtland. It calls for such development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. The main goals to be reached in the frame of sustainable development are:

- Ensuring the availability of basic goods which are essential for life of the present and future generations, including an equitable access to raw materials [1]-[5].
- Ensuring the caring ability of the environment to sustain the existence of human civilisation, especially in term of the environment quality [6]-[8].

Although this definition of sustainable development was formulated in 1987, the roots of the idea can be found in the works of Hans-Carl von Carlowitz, who in 1713 suggested the trees feeling should only be carried out on such a degree that makes it possible to regrow them in the foreseeable future. The development of human civilisation was based on the use of natural resources in an uncontrolled manner, without taking into account degradation of the environment and what is as well important without considering an interest of the future generation. Generally, sustainability is based on the integration of environmental management social and economic goals, mainly reduction of poverty. The main aim of sustainability is to interlink the ecological and socio-economical border in pathway of developments to assure the ecological, social and economic stability [5], [8]-[12]. Only the development that is based on the consumption of resources which does not lead to their exhaustion and offering their use for all people constitutes an important paradigm of the global justice. Undoubtedly, energy supply is and will be one of the key factors governing the development or even survival of the human civilisation. Its consumption has grown over the last decade by 15,4% (see Table 1).

In the case of Poland, the consumption of primary energy grew rapidly from 1950 to 1980 due to the development of mostly heavy industry, similarly to other socialist countries. After the transitioning from the socialist to capitalist system, which started in 1990 through the introduction of so-called Balcerowicz Plan, a number of industrial plants went bankrupt, resulting in a significant decrease in...
the consumption of primary energy in 1990-2015 from 100.6 Mtoe to 94.6 Mtoe/year, i.e. by 5.7% (see Table 2).

Table 1. Characteristic of global primary energy consumption 2006-2016.

| Year | Total primary energy (Mtoe) | Total renewable energy (Mtoe) | Total biofuels (Mtoe) |
|------|-----------------------------|------------------------------|----------------------|
| 2006 | 11 267                      | 93                           | 28                   |
| 2007 | 11 627                      | 107                          | 38                   |
| 2008 | 11 784                      | 123                          | 50                   |
| 2009 | 11 602                      | 144                          | 56                   |
| 2010 | 12 170                      | 170                          | 64                   |
| 2011 | 12 455                      | 204                          | 66                   |
| 2012 | 12 621                      | 239                          | 67                   |
| 2013 | 12 866                      | 280                          | 72                   |
| 2014 | 12 989                      | 317                          | 80                   |
| 2015 | 13 105                      | 367                          | 82                   |
| 2016 | 13 276                      | 402                          | 82                   |

Table 2. Total consumption of primary energy in Poland (Mtoe).

| Year | Mtoe |
|------|------|
| 1950 | 28.6 |
| 1960 | 54.4 |
| 1970 | 84.7 |
| 1980 | 124.5|
| 1990 | 100.6|
| 2000 | 89.8 |
| 2006 | 94.1 |
| 2007 | 92.7 |
| 2008 | 95.4 |

Table 3. Characteristic of primary energy consumption and CO₂ emissions in Europe and selected countries (Listed from the biggest emitters of CO₂ per capita).

| Country               | MgCO₂/capita/year | Primary energy consumption, Mtoe/year |
|-----------------------|-------------------|---------------------------------------|
| Czech Republic        | 10.7              | 43.4                                  |
| Netherlands           | 10.5              | 77.4                                  |
| Belgium               | 9.9               | 59.1                                  |
| Germany               | 9.1               | 311.8                                 |
| Austria               | 8.1               | 33.0                                  |
| Poland                | 7.8               | 101.9                                 |
| United Kingdom        | 7.1               | 188.1                                 |
| Italy                 | 6.5               | 167.4                                 |
| Spain                 | 5.9               | 125.6                                 |
| France                | 5.0               | 252.8                                 |
| Sweden                | 4.8               | 49.0                                  |
| Australia             | 17.4              | 122.9                                 |
| USA                   | 16.9              | 3191.2                                |
| Canada                | 15.4              | 251.9                                 |
| Korea                 | 11.8              | 260.4                                 |
| Russian Federation    | 11.7              | 731.8                                 |
| China                 | 5.9               | 2727.7                                |
| Mexico                | 4.0               | 186.2                                 |
The best parameter characterizing the impact of primary energy consumption by individual countries is the amount of annual CO\textsubscript{2} emissions per capita. The selected EU countries and other biggest emitters of CO\textsubscript{2} are depicted in Table 3. The data shows that the highest CO\textsubscript{2} emissions per capita come from Australia, the USA and Canada, while the lowest come from Mexico, Sweden, France, Spain and China, although the total CO\textsubscript{2} from China is the highest (10.6 mln Mg CO\textsubscript{2}/year, i.e. 29.31% global emissions in 2015), due to the largest population. For example, the CO\textsubscript{2} emissions from Poland per capita per year account for 7.8 Mg CO\textsubscript{2} per capita. Burning primary energy sources is responsible for 3 main air pollutants in Poland, i.e. SO\textsubscript{2}, NO\textsubscript{x} and CO\textsubscript{2}. Due to the economic changes caused by the transition from the socialist to capitalist system in 1990, a substantial decrease in SO\textsubscript{2}, NO\textsubscript{x} and CO\textsubscript{2} emission occurred, mainly resulting from the bankruptcy of large industrial plants in 1990-2000 (see Table 2).

As was mentioned, the problem with energy is not only its effect on climate change but as well exhaustion fossil fuels reserves. According to the forecasts, the estimated reserves of coal are approximately 1140 billion Mg and will suffice for about 114 years, the reserves of crude oil amount to 1701 billion barrels and will be enough for roughly 51 years, whereas the reserves of natural gas in amount of 190 trillion m\textsuperscript{3} which will be sufficient for 52 years [13]. Therefore, developing the renewable energy sources is necessary not only from the point of view of climate protection, but also to ensure new energy sources for our civilisation. The development of renewable energy may mitigate these threats. Global use of renewable energy grows from 93 Mtoe = (0.83\%) in 2006 to 402 Mtoe (3.03\%) in 2016 (see Table 1 and 2). One of primary energy resources are biomass of which biofuel becomes the most important. Its consumption is growing from 28 Mtoe (0.25\%) in 2006 to 82 Mtoe (0.62\%) in 2016 [13]. Application of biomass as a primary energy source varies greatly between the developing and the developed countries. The developing countries mainly utilize biomass – especially wood – as one of the basic sources of primary energy, whereas the developed countries are developing advanced methods of biomass use for energy purposes, primarily including the production of biogas and liquid biofuels, i.e. ethanol and biodiesel. These advanced biofuels are usually produced with biomass from special plantations [13]-[17].

While having a discussion about the environment, we usually think about the natural environment and ignore the human environment, which includes an equally important component of socio-economic relations. The development of biofuels exerts a significant influence on the functioning of societies [18], [19].

2. Socio-economic consequence of biofuel development.

Focusing the energy policy only on mitigation of the CO\textsubscript{2} emission threatens the sustainable development paradigm i.e. intra-generational equity, which demands equitable access to food for all people. The food demand will continue to increase for two reasons: growing human population and greater number of better-fed people. At present, 250 thousand people starve to death each day, while 780 million people in developing countries and 27 million people in developed countries are malnourished. In such situation, devoting large areas of land for the biomass used for fuel production raises moral concerns. This is especially relevant in the context of biofuels from agricultural crops. According to the European Commission decision from 2009, as much as 10\% of energy used in transportation should be obtained from biofuels. In order to make biofuels a viable solution, European governments subsidize powerful industrial and agricultural lobbies. For instance, by 2020 each person in Great Britain will pay approximately £35 per year (£1-2 billion in total) for biofuel subsidies, while in Germany – roughly €30 (€1.4–2.2 billion in total). Also in the United States, the production of ethanol (mainly from corn) which is used as fuel additive developed rapidly thanks to subsidies. In 2011, as much as 127 million tons of corn, i.e. 40\% of annual production was devoted for bioethanol production. Allocating such a great amount of corn for ethanol production in 2007–2012 caused a 100\% increase in the prices of corn. Large import of crops for biofuels by the European Union caused a dramatic 2.5-fold increase in the food price index. The increase in food prices is especially severely felt by poor people, who spend most of their income on this basic commodity.
In the light of the above-mentioned statements, utilizing biomass from agricultural crops as a source of energy endangers the implementation of sustainable development, as it violates the intra-generational justice paradigm by limiting the access to food for the poor.

3. Environmental consequences of biofuel development.

The promotion of biofuels is based on wrong assumption that their combustion releases equal amount of CO\textsubscript{2} to the one absorbed earlier by plants. This oversimplification does not take into consideration the entire biofuel production cycle. The effects of land use change and energy outlays for the cultivation and processing of biomass used in fuel production are omitted in the calculations [17].

A pressure put on the usage of biofuel in transportation, exerted especially by the European Union policy, resulted in the deforestation of tropical forests to clear land for cultivation of biofuel plants – especially in the developing countries [18]. According to the research conducted by Danielsen [13], the absorption of CO\textsubscript{2} by tropical forests is much greater than the one of plants grown in their place. Consequently, the biofuel production decreases CO\textsubscript{2} absorption on the lands of felled tropical forests. Transforming tropical forests for the cultivation of biofuel plants leads to an additional emission of 55 Mg CO\textsubscript{2} annually per hectare for the period of 120 years.

Moreover, in order to produce biofuel, e.g. corn bioethanol, it is necessary to provide energy for the cultivation, fertilizer production, plant collection, as well as fuel processing through fermentation and distillation. By using the life cycle assessment technique, it was shown that the amount of the emitted CO\textsubscript{2} per unit of energy obtained from corn ethanol is 60% greater in relation to the CO\textsubscript{2} amount emitted in combustion of the equivalent petroleum-based fuels. Even in the case of sugar cane ethanol produced in Brazil, where the industry is most advanced and where the leftover biomass is entirely used, e.g. sugar cane stalks are burned for heat energy; it was not possible to decrease emission of CO\textsubscript{2} to a lower level than the one of oil-based liquid fuels. However, in the case of Brazil, the development in sugar cane ethanol helped to create approximately 700 thousand new jobs, which can be considered a positive effect increasing the social sustainability. It allowed Brazil to become independent from the liquid fuels import, and the price of ethanol is competitive to the one of petrol. In Brazil, it was possible to achieve sustainable access to liquid fuels for transportation.

The full analysis of biofuel production cycle showed that cultivation of some plants for biofuel production, such as rape, requires application of large amount of fertilizers which increase the emission of another greenhouse gas; namely, nitrous oxide, thus contributing to the greenhouse effect. In the case of rape, the nitrous oxide may increase the greenhouse effect by as much as 70%. The development of biofuel plant cultivation destroys habitats and biological diversity. The forests in south-eastern Asia, which provide habitats for a plethora of various organisms, are the most endangered by the biofuel plant plantations. It is estimated that the number of species living in the area decreases fivefold when forests are cut and turned into biofuel plantations.

Production of liquid biofuels for the transportation also has a negative impact on the aquatic environment due to a high consumption of water both for watering plants and during their processing to biofuels. Moreover, the processing involves production of large quantities of hazardous wastewater, e.g. production of 1 litre of ethanol generates to 6–12 litres of highly contaminated wastewater. Meanwhile, water shortage in that regions is already negatively influencing food production.

Generally, approximately 2500 litres of water are used in order to obtain 1 litre of biofuel. Such amount of water is enough to produce food for one person. In order to irrigate 30.000.000 hectares of land for biofuel cultivation, roughly 180km\textsuperscript{3} of fresh water will need to be used. One must bear in mind that due to the growth of population to 8.3 billion in 2030 (from 7.2 billion in 2012), food, water and energy demand will increase by 35%, 40% and 50%, respectively. Large monocultures, which are usually used in the case of biofuel plants, require wide application of herbicides and pesticides, which then infiltrate to ground waters – contaminating them. Soybean farming in Brazil is an example of a negative effect of pesticides. Along with herbicides, they are used on a large scale in the Pantanal wetland, which constitutes one of the most important habitats for hundreds of birds, mammals and reptiles. Another example includes 20,000 hectare sugar cane plantation, intended for ethanol production, which is located in the delta of Tana River in Kenia. With the planned water uptake of...
1680 m³ water/min, which equals 30% of river flow rate, it seriously threatens the local ecosystem which is a habitat to 345 species of water and marsh birds.

4. Conclusions
1. Attention was drawn to the fact that the development of civilization is threatened not only by the excessive CO₂ emission from the combustion of fossil fuels, but also by their depletion.
2. In such case, it is necessary to develop other energy sources, including renewable ones.
3. There is no doubt that the development of renewable energy sources may mitigate climate changes on the one hand and ensure the adequate supply of energy for the proper functioning of our civilization on the other.
4. It was pointed out that the cultivation of energy crops for the purpose of biofuel production may also have negative consequences, because:
   - rain forests, which absorb significant amounts of CO₂, are cut down in order to acquire land for the cultivation of energy crops,
   - increasing the area of subsidized energy crops cultivation will limit the food production, resulting in the increased food prices.

5. References
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