Universidade de São Paulo
Escola Superior de Agricultura "Luiz de Queiroz"
Departamento de Economia, Administração e Sociologia
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Energy and economic effectiveness of biomethane production and utilization in the Czech Republic: a case study for two different regions

Hélio Antonio Basso do Prado

Trabalho de conclusão de curso
apresentado para obtenção do título
de Engenheiro Agrônomo pela
ESALQ - USP

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Abstract

This project deals with the evaluation of the energy and economic effectiveness of biomethane production and utilization in the Czech Republic, based on a fuel cycle approach, that is,

technologies used for production of end-use energy products, as Biomethane and Combined Heat and Power (CHP) plant – heat and electricity production. The energy effectiveness approach is based on the calculation of the net energy effect resulting from the use of 1 ha of agricultural land while the economic effectiveness concerns parameters of the individual elements of the fuel cycle. The input data needed for this approach was maize silage production potential, which was developed using a detailed spatial (GIS) methodology and applied in two different regions (Hodonín and Strakonice), regarding their climate and soil conditions, and for two different scenarios, current situation of biodiversity of crops on agricultural lands of both regions (2014) and future target of variability of crops on agricultural lands (2050). It is possible to see that biomethane production is more effective than CHP, with lower specific production costs and higher energy efficiency.

Key words: biomethane, biomass, biogas, renewable energy

1. Introduction

Opinion formers have brought an interesting and important subject in the past years around the globe: the impact of human activities on the environment and its biodiversity, on the atmosphere and, consequently, our own quality of life, and, finally, on next generations social lifestyle. Since Stockholm Conference, in 1972, by United Nations Organization (UNO), world leaders have been discussing these issues, trying to find a good way for solving them, and after the recent Paris Agreement, in 2015, many countries have turned their efforts towards reaching the proposed targets. Europe Union is an ambitious contributor to global attempts in order to reduce Green House Gases (GHG) emissions and fight against climate change: one of the targets set by EU was the increase of the share of renewables in energy supply to a level at least 27% of total consumption.

Renewables types of energy are characterized by its rapidly replacement based on natural processes and by its lower impact on the environment. Photovoltaic system, wind energy, hydropower plants, ethanol production and energy cogeneration from biomass are some examples of renewables and each one of these are related to a specific type of natural process: sunshine, wind quality, water availability and arable land availability. The variability of natural processes is the reason why renewables may be limiting for some countries, who, for instance, does not own many hours of sunshine or vast availability of water. Biomass, however, is possible to be cultivated in any country as long as this one presents arable land.

In the case of Czech Republic, due to its modest size and also to geological formation, arable and agricultural land is considered as a limiting resource to biomass production. Besides, some part of the year, the country presents frost seasons or low sunshine levels, which also impact agricultural yield. Issues as these ones bring some discussions concerning land usage, either to conventional agricultural (food production and supply) or to agriculture and forestry production to energy purposes. Therefore, there is a need for planning policies of land usage in countries like the Czech Republic, where strategic information as mapping best places for cultivating conventional or energy crops is fundamental to reach both targets: food supply and biomass share increase in energy consumption.

Biomass functions as an input to many types of end-use products of energy. It can be directly burned and transformed into electricity, heat or steam, or even converted into intermediate products, like biofuels, pellets/briquetts, or biogas. An interesting approach of this last one is the fact that it may be used for different purposes. Biogas can be used for cogeneration, in industrial usage, within natural gas network, as vehicle fuel, etc. Summarizing, it can be transformed in heat and electricity, in Combined Heat and Power (CHP) plants or

upgraded into biomethane. The lasts experiences of biogas complex have shown that, mostly of the years, its business is directed to the CHP branch, and biomethane production is still incipient. In this context, a study that compares both energy and economic effectiveness of Biomethane and CHP plants is necessary for planning of biogas complex activities and purposes.

In Brazilian case, a country who presents vast availability of arable land and potential for developing its share of renewables in energy supply, should explore, as much as possible, its resources to attend long-term targets, like those previously described, towards a politically and environmentally correct development supply of energy. A study like this brings an important point of view to expertise new sources of clean energy, in order to diversify the energy portfolio and strengthen them in market. Thus, becoming even more competitive in relation to fossils.

2. Literature review

2.1 The role of renewable energy in Europe Union and in the Czech Republic

Climate change has a significant importance in the whole world because of its impacts on ecosystems, the economy, society and human health. As responsible of its occurring, men need to deal with the consequence of the climate change while trying to counter its causes. According to Eurostat, "Anthropogenic climate change, or in other words climate change caused by humans, is a result of Green House Gasses (GHG) emissions due to human activities" and "the Europe Union is an ambitious contributor to the global efforts to fight climate change and reduce GHG emissions".

Besides households' consumption, all economic processes involve the use of energy in their activities, which means that it also involves GHG emissions. A clever way to decrease these emissions is to switch traditional energy production to cleaner forms of energy, as renewables. This strategy will, therefore, avoid carbon emissions to the atmosphere. An article from the German Environment Agency (2018) shows that from 1990 to 2017, the amount of carbon equivalent released in the atmosphere was avoided in six times with renewables instead of fossil fuels usage. The following figure details it.

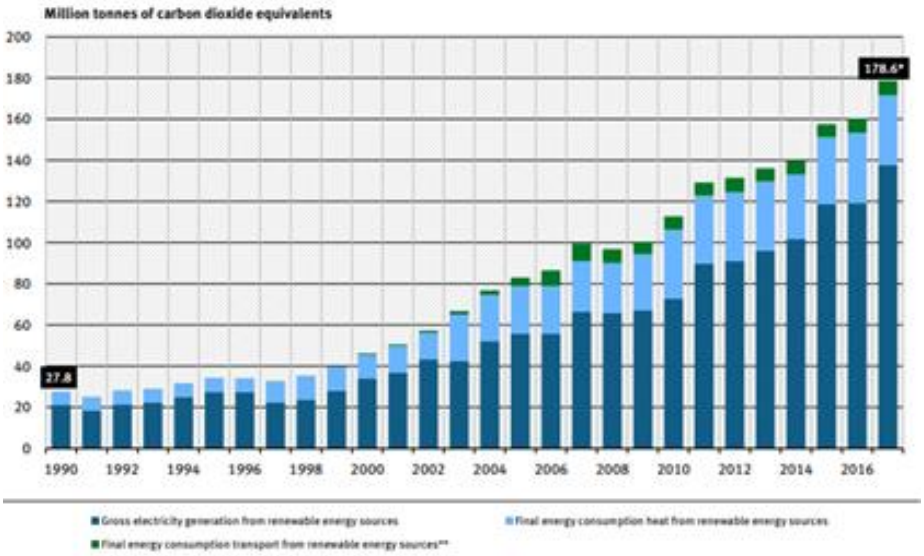

Figure 1. Greenhouse gas emissions avoided from 1990 to 2017 through the use of renewables. Source: Federal Environmental Agency of Germany

The total available energy in the Europe Union is not completely produced from its members. Part of its demand is supplied with imports from third countries. In 2016, for instance, the Europe Union produced around 46% of its own energy, while 54% was imported. The energy mix of this year was divided by five different sources: petroleum products (35%) - fossil fuels, usually in liquid state, and crude oil and all products derived from it -, natural gas (23%), solid fuels (15%) - fossil fuels covering various types of coals and solid products derived from it -, nuclear and renewable energy (13% each). The energy mix for the Czech Republic, in the same year, was sorted by solid fuels (40%), petroleum products (20%), natural gas (17%), nuclear energy (15%) and renewable energy (10%), as shown in next figure.

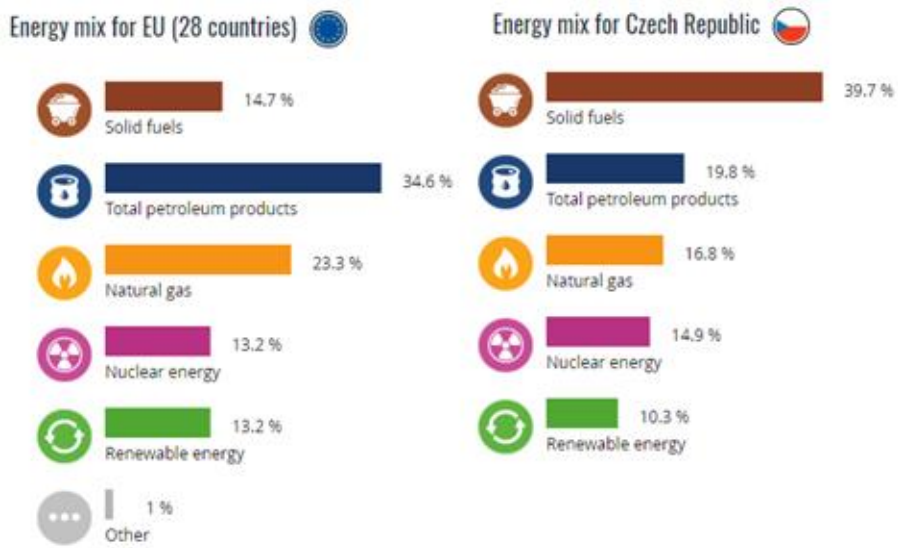

Figure 2. Energy mix for Europe Union and in the Czech Republic in 2016. Source: Eurostat

In this context, Europe Union set out a framework for climate and energy policies with targets to be reached in 2030. Among all of them, the framework proposes actions as the commitment to continue reducing greenhouse gas emissions, setting a reduction target of 40% by 2030 relative to 1990 levels; a renewable energy target of at least 27% of energy consumption, with flexibility for member states to set national targets; to improve energy efficiency through possible amendments to the energy efficiency policies.

2.2 Biomass within RES and maize silage as a biomass source for biogas production

The renewable portfolio for energy usage presents various options of production systems. Defined as an energy resource that is rapidly replaced through natural processes, there are many types of renewable energy resources, such as solar energy (photovoltaic systems), wind energy, geothermal energy, hydropower, biomass and so on.

Despite the differences among all types of energy resources, biomass is characterized by its advantages over other Renewable Energy Sources (RES), for instance, its logistics and usage (the possibility of storing and transporting it), low dependence on immediate weather conditions (in contrary to PV or wind system), good potential for countries with vast availability of arable land, like Brazilian case, etc. (Vávrová, K. et al., 2016). Besides these comparisons, biomass provides adaptation of the crop to be utilized in determined land, according to different edaphoclimatic requirements among agricultural crops.

Knápek et al. (2015) defines biomass as an energy source of many different subcategories, as residual material from industry and service sectors (wood processing industry, for instance), residual from agricultural production (residual straw), plantations of perennial and non-wood plants (Mischanthus is well known in the conditions for Czech Republic), annual agricultural crops (maize is, currently, the preferred type of biomass as the standardized input for biogas stations), and others. Besides, Hutnan, M. (2016) considers maize as a suitable energetic crop for biogas production, since it provides, in the form of maize silage, high yields: 10 – 30 tons of total solids (TS) per hectare.

2.3 Energy and economic effectiveness of biogas complex production

The domestic biogas market has been experiencing great development in recent years in Europe and in the Czech Republic. Thanks to the reception of the act on supporting the Production of Electricity from Renewables and to the Implementation of investment support from national programs co-financed by the EU, the number of biogas plants has increased, in CR, from a few operations to 150 installed stations exceeding 100 MW in 2011 (Kyselák et al., 2011). In contrast, Brazilian panorama of biogas market is still growing, since "there is a

distributed generation market (of electricity) with huge potential in Brazil, where biogas has a great advantage" (Gardenmann, 2017).

At this context, the development of methods of studying and applying effectiveness, regarding either energy or economic point of view, to this sector is crucial to its growth and consolidation in Europe or in Brazil. Kysek et al (2011) presents an idea of how to define energy efficiency, where the input energy in the system, resulting from decomposition of biomass delivered to the biogas plant, is expressed as gross energy in biogas (**QBPbrutto**). The gross energy is deducted from the technology consumption of electricity and technology's own consumption of heat and, then, supplied to the distribution network as net eletricity supply (**Edod**) and net heat supply (**Qdod**). The indicator called “Biogas Energy Efficiency Level” (**SEVbp**) is calculated as:

$$SEVbp = (Edod + Qdod) / Qbp,brutto$$

Pavlíček, P. (2016) defines energy efficiency as the ratio of produced and input energy into the production process, considering, though, the overall energy of the fuel cycle. The fuel cycle begins with the cultivation of biomass, where should be regarded the use of fossil fuels for cultivation and transportation of the biomass. Then, the loss with storing the biomass should also put in count. Finally, the losses of conversion into biogas and into the transformation of the final product (either biomethane or Heat and Power) allow a detailed energy output effectiveness. For instance, the energy content of biomethane injected into the natural gas grid.

In his thesis, Pavlíček considers the economic effectiveness as an assessment from the point of view of the invested capital or from the perspective of the investor. To evaluate the effectiveness of a biogas plant implantation project, he uses 4 different criteria: Net Present Value (NPV), Internal Rate of Return (IRR), Payback period and Minimum Price per Unit of Production. His analysis approaches all conditions that must be accepted to approve the construction of a biogas plant.

Other assessment that should be taken in count is the economic effectiveness of biogas production from the point of view of those who already make business on this sector. Those people who has a biogas plant and wonder whether to switch the portfolio of production or not. In other words, "is it worth to produce biomethane instead of a heat and power?". Knápek et al. (2015) presents a methodology where is possible to calculate specific costs of production of one unit of energy of energy (kWh in final products) that allows an investor to compare differences in cost production of Biomethane and Heat and Power.

3. Goals and objectives

The main goal of this project is to compare whether biomethane is worth than CHP in biogas industry business, in terms of energy and economic efficiency, through an application a Fuel Cycle Methodology, that is, an approach of energy and economic effectiveness on a case study: two scenarios of biomethane and CHP production – in 2014 and 2050 –, in two regions with different soil and climate conditions and different energy market: Hodonín and Strakonice. At the end of the results, it will be possible to evaluate how much energy is lost and consumed during the production process and how much costs to produce it in each case.

4. Methodology

The methodology of this project is divided in two steps: firstly, the estimation of biomass production in both regions, previously mentioned, using high resolution spatial data and modelling biomass potential, checking specifically maize silage as a source; Then, the application of the energy and economic effectiveness (Fuel Cycle Approach) of biomethane and CHP production in each scenario created in the first part of the methodology.

4.1 Biomass potential from maize silage

The input data for the application of the Energy and Economic Effectiveness approach on a case study is the available biomass used to produce energy, which is, in this case, maize silage. Also, in this assessment it was possible to create 4 scenarios to each region: with consolidated and projected data for 2014 and 2050, respectively, regarding different variabilities of cultivated crops in both regions and the biomass potential from maize silage assessed around 10 km and 50 km of biogas plants. The following figure details the structure of the assessment.

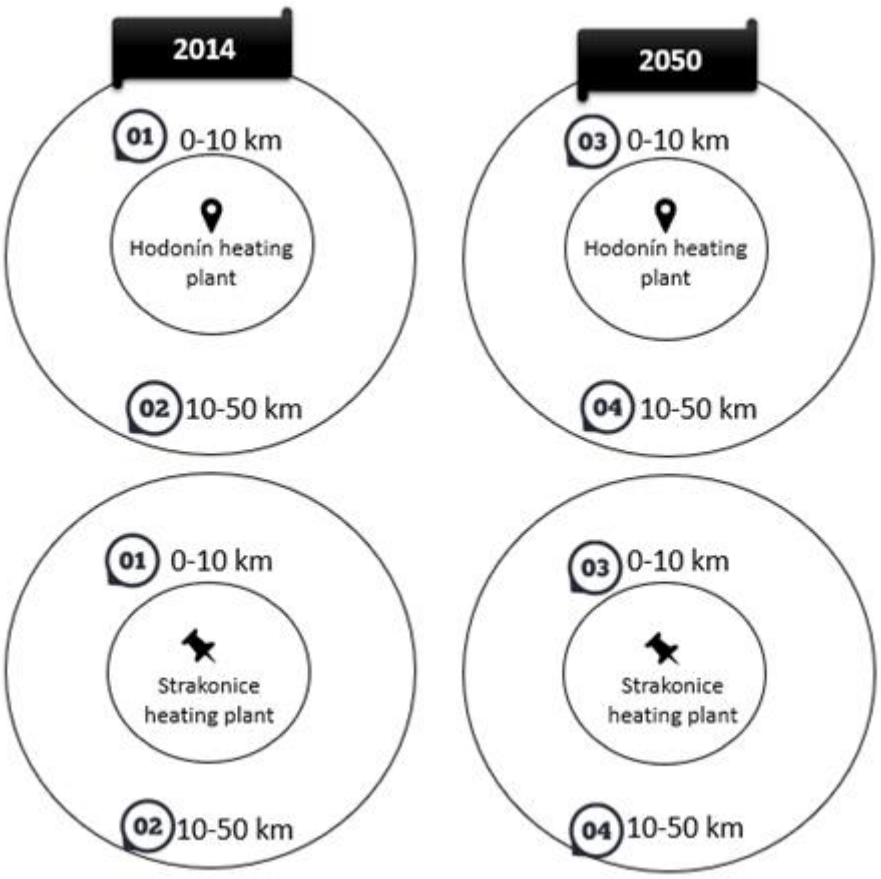

Figure 3. Structure of four scenarios for each region, based on the data, either consolidated or projected, and on the area around the biogas plant. Source: Developed by the author.

The methodology used for the determination of biomass potential was based on a bottom-up approach, which means that biomass from energy crops, forests and residual of agricultural crops is estimated from the sum of yields calculated from a relation between climate and soil conditions of land plots used for energy purposes. It is important to highlight the identification of an individual land plot (through Land Parcel Identification System – LPIS) and the classification of the climate and soil condition to each land plot. Each uniquely identified "piece of land" will be characterized by a five-digit numerical code (which is called Valuated Soil-Ecological Units – VSEU or BPEJ in the Czech Language), where the structure of the code is:

V.XX.YZ

where:

V… reflects the climate region (10 different climate regions are defined in the Czech Republic based on daily average temperatures, annual precipitation, probability of dry periods)

XX… indicates the so-called main soil unit (soil physical and chemical characteristics, approximately 78 different categories are defined)
Y… indicates a combination os slope and plot orientation of the soil (north, south…)
Z…. indicates a combination of soil profile and its skeleton

Climate region and main soil unit – the first three digits of the code – form over 550 so-called main soil and climate units (MSCU), which were used in the methodology as main characteristic of agricultural land quality. For these units an expected yield of conventional crops – annual crops for food production – were calculated as average yields from statistical yearbooks for three categories of land suitability types related to units of Czech agricultural soil valuation (MSCU).

The next move is to determine the share of energy crops that would be considered in the model, respecting the demand and production of conventional agriculture (crops for food) for the Czech Republic`s needs. Based on this, the model will consider available land for conventional agriculture and for energy crops, which makes possible the allocation process: the distribution of conventional crop into individual plots (farming blocks) so that the total acreage for each kind of conventional crop should be reached (total acreage is based on regional statistics of cultivated area for each crop) and respecting the order of priority of crops with higher demand for soil quality. The allocation of energy crop should follow the same step.

At the end, the potential of biomass from maize silage is basically the sum of total yields of land plots where maize for energy purposes was allocated, highlighting that this result was calculated for the four previous mentioned scenarios. The following figure details the structure of biomass potential by modelling it with high resolution spatial data.

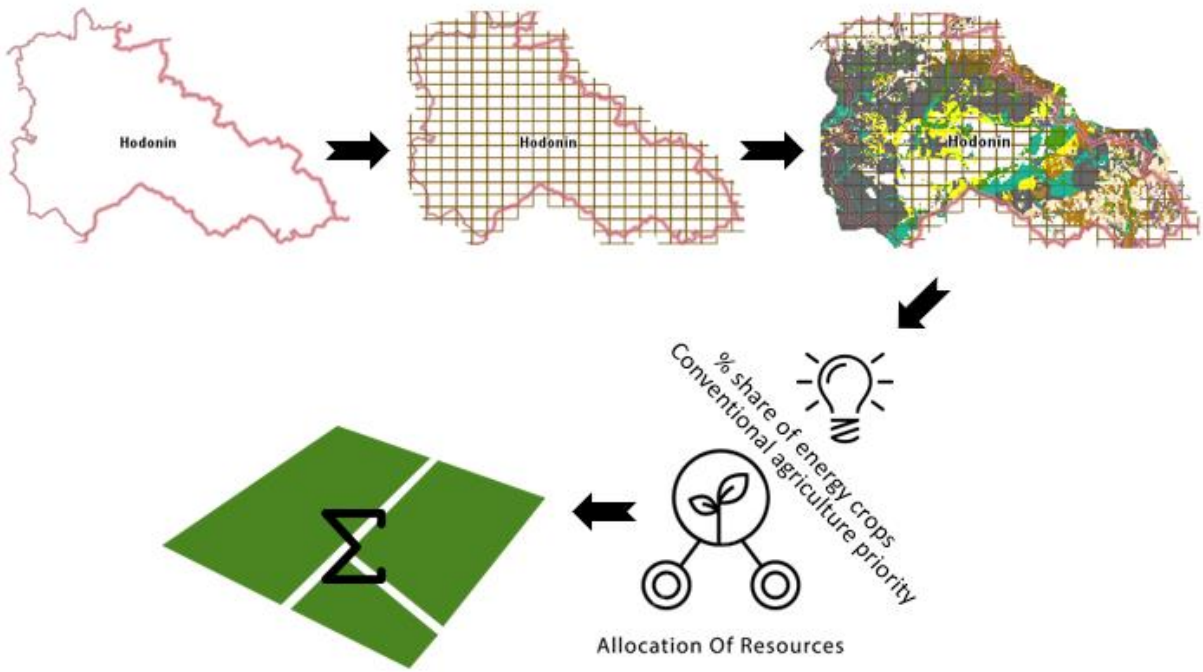

Figure 4. Summary of biomass potential using high resolution data of climate and soil conditions. Source: Developed by the author.

4.2 Energy and economic effectiveness – Fuel cycle approach

The evaluation of the use of energy biomass from the system point of view is based on respecting the whole biomass fuel cycle, that is, starting from biomass production, through every conversion processes (the transformation of biomass in biofuel, for instance) until the use of biomass for production of different forms of end-use energy. The systematic view also means that the whole life-cycle of each part of the fuel cycle needs to be correctly evaluated, from economic and energy point of view.

4.2.1 Energy approach

The biomass fuel cycle is defined as a set of individual stages from biomass production on agricultural land until the transformation of biomass into intermediate products and, further, into energy products for final energy consumers. For instance, in the case of maize used as the input of biogas stations, the biomass is firstly transformed into biogas (intermediate product), which will be used to produce a useful product for the end-consumer: Biomethane or Combined Heat and Power (CHP).

This methodology considers agricultural land, energy needed for the production of biomass and end-use energy products, and financial sources to carry out individual stages of the fuel cycle. In order to estimate the effectiveness of an end-use energy product, it is necessary to deduct own technological consumption and any other energy losses to each process. The following figure details the methodology of energy effectiveness.

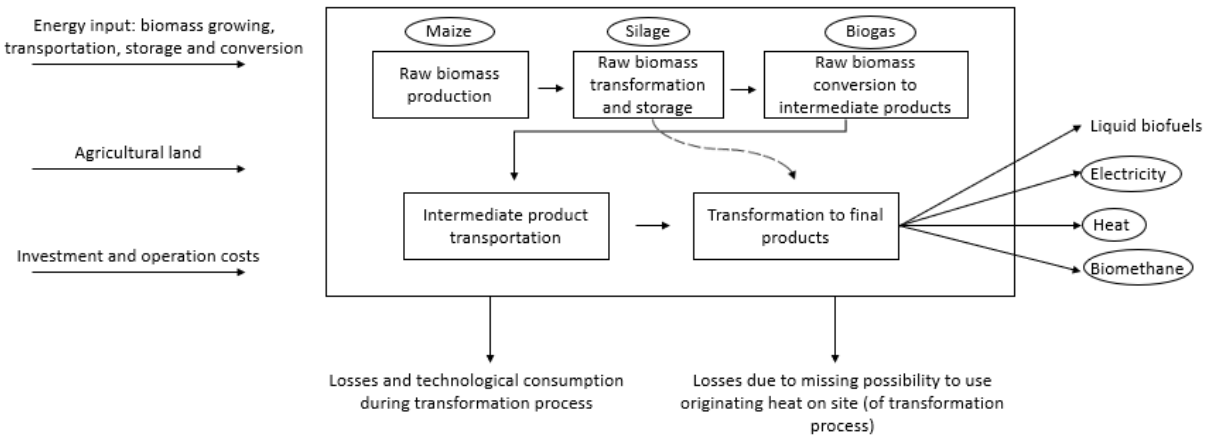

Figure 5. Detailed structure of energy effectiveness methodology. Source: Adapted from Knapek et al. (2015)

The energy effectiveness approach considers the energy flow and losses of all processes of end-energy products cycle. On a superficial look, energy effectiveness is expressed as a ratio of energy produced per unit of agricultural land and energy contained in end-use products. The assessment starts with the production of biomass in field. In the case of this project, the gross production of energy in maize (BEG) from one hectare of land can be expressed as:

- $BEG = Y \cdot HV\ [GJ.ha^{-1}]$ (1)

where BEG is the energy gain of one hectare of land cultivated with maize [$GJ.ha^{-1}$], Y is the hectare yield of this crop [$t.ha^{-1}$] and HV, the heating value of this biomass on a specific moisture and share of dry matter [$GJ.t^{-1}$]. The energy losses during maize transportation and storage (silage production) are reflected by the coefficient CELts:

- $CELts = 1 - \frac{BEGts}{BEG}\ [GJ.GJ^{-1}]$ (2)

where BEGts is the energy content in maize silage after transportation and storage [GJ] and CELts is the specific energy loss in the biomass transportation and storage. The third stage of the fuel cycle is its conversion to intermediate product, which is biogas production through anaerobic fermentation of maize silage, in this case. The energy efficiency of biomass transformation into intermediate product is expressed by the coefficient CELcip:

- $CELcip = 1 - \frac{BEGip}{BEGts}\ [GJ.GJ^{-1}]$ (3)

where BEGip is the energy content in maize silage after conversion into the biogas [GJ] and CELcip is the specific energy loss during the conversion process of maize silage to biogas [$GJ.GJ^{-1}$]. The next step of the fuel cycle is the deduction of energy consumption due to transportation of the intermediate product to the place where it is transformed into the end-use energy product. In the Czech Republic, most of biogas plants have their own cogeneration unit,

which is located at the same area of the plant, and the biogas is directly utilized on the site as an input for production of CHP or Biomethane. Therefore, the energy consumption for the transportation process is rejected. The equation, though, can be used for any other type of end-use energy that presents transportation of intermediate products to the site where it will be transformed:

- $\mathrm{CELtp} = 1 - \frac{\mathrm{BEGtp}}{\mathrm{BEGip}}$ [GJ.GJ^{-1}] (4)

where CELtp is the specific energy loss in the intermediate products transportation and storage [GJ.GJ^{-1}] and BEGtp is the energy content in a specific intermediate product after its transportation and storage [GJ]. The fifth stage of the fuel cycle is the transformation of intermediate product, or directly biomass, into useful end-use products. Efficiency of such transformation is expressed by the coefficient CELtfp:

- $\mathrm{CELtfp} = 1 - \frac{\mathrm{ECfp}}{\mathrm{BEGtp}}$ [GJ.GJ^{-1}] (5)

where CELtfp is the specific energy loss in transformation of biogas (intermediate product) or directly biomass into final products [GJ.GJ^{-1}] and ECfp is the energy content in biomethane or CHP as final products [GJ].

The energy content in these final products is a gross indicator. It means that it has not been corrected by its own energy consumption during all processes, for instance, heat consumption in the fermenter, technological electricity consumption or even fuel consumption for maize harvest. Besides, it is also important to consider the share of unused energy. In the Czech Republic, many biogas stations are located in low density areas, which means that part of the produced heat, that achieves long-distance consumers, becomes uncompetitiveness in market, since its deliver costs becomes higher. So, as there is no local demand, the heat is basically lost. In contrast, for instance, electricity might be supplied in the distribution system and does not have the same problem as heat.

Technological own consumption of energy, in industrial processes, is expressed by the coefficient CESCtfp, which is defined as the relative share of energy consumption for technological purposes on total amount of energy in end-use produtcs:

- $\mathrm{CESCtfp} = \frac{\mathrm{ESCfp}}{\mathrm{ECfp}}$ [GJ.GJ^{-1}] (6)

where CESCtfp is the specific energy consumption of transformation technology [GJ.GJ^{-1}] and ESCfp is the own consumption of energy (electricity, heat, etc.) for technological purposes [GJ]. The rate of unused energy of Biomethane or CHP is expressed by the coefficient CELnupf, a ratio of non-used energy of these products after their conversion process and total

amount of energy in these end-use products potentially available to be delivered to final consumers:

- $CELnufp = \frac{ENUfp}{ECfp}$ [GJ.GJ^{-1}] (7)

where CELnufp is the coefficient of unused energy of end-products [GJ.GJ^{-1}] and ENUfp is the amount of unused energy in a specific type of end-use product [GJ]. Finally, the energy consumption of individual stages of the fuel cycle should also be deducted from the gross energy efficiency:

- ECBEG: Energy consumption for biomass production – it is assumed the consumption of fuels for agrotechnical machinery operations and short-distance transport from field. [GJ.ha^{-1}]
- ECts: Energy consumption for biomass transportation and storage. This is related to the closeness of agricultural land and the place where biomass would be storaged and the type of storage, for example silos (common for biogas stations). Therefore, the consumption might be minimum, and, in some cases, it can be rejected. [GJ.ha^{-1}]
- ECcip: Energy consumption for the conversion of biomass (maize silage) to intermediate products (biogas). Examples: energy consumption for drying pellets or heat for heating the fermenter (biogas stations). [GJ.GJ^{-1}]
- ECtp: Energy consumption of transportation and storage of the intermediate product. It means the biofuels consumption to places where it will be used for transformation into end-use products. The consumption may be rejected whether the intermediate product is used directly in the place of its production, as biogas stations and cogeneration units case. [GJ.GJ^{-1}]
- ESCtfp: Own energy consumption of equipment/machinery to transform biomass or intermediate product (biogas) in end-use energy products (Biomethane and CHP). [GJ.GJ^{-1}]

The total net effectiveness resulting from production of a specific type of biomass (maize silage) on 1 ha of agricultural land, assuming a particular technology for the conversion into intermediate product (biogas through anaerobic fermentation) and a specified technology of transformation (Biomethane through purification of raw biogas) into the final product is defined as:

- BEGnetto = BEG · (1 – CELts) · (1 – CELcip) · (1 – CELtp) · (1 – CELtfp) · (1 – CELnufp) – ECBEG – ECts – ECcip – ECtp – ESCtfp [GJ.ha^{-1}] (8)

4.2.2 Economic approach

Individual steps of the biomass production fuel cycle are accompanied with respective costs for their accomplishment. When assessing the effectiveness of different types of biomass or different end-use products from the same biomass, it is essential to consider not only the energy efficiency itself, but also the economic effectiveness of those end-use energy products. When assessing economic effectiveness of different uses of biomass to produce energy, it is necessary to consider the following principles:

- Lifetime of the main equipment must be respected
- All costs induced by processes in a given cycle have to be covered
- Market price of all inputs has to be used
- Adequate rate of return on invested capital must be respected

An important input in economic effectiveness evaluation are the costs of conversion technologies, that is, conversion of biomass into intermediate products, and technologies for biomass (or intermediate products) transformation into final products. It is about a comparison of effectiveness of different technologies usage from the same biomass type, which means, in this case, a comparison between Biomethane and CHP general production costs. Using the same input data from energy effectiveness approach, it is possible to estimate the specific costs in the final product, which does not include the deduction of used energy for biomass production, transportation and storage, since this indirect consumption (loss energy) enters in the calculation of biomass production cost.

The specific costs of production of one unit of energy from a specific type of biomass using a particular transformation technology are calculated as:

- $\mathrm{SCPE} = \frac{\mathrm{BP} \cdot 3{,}6}{(1-\mathrm{CELcip})\cdot(1-\mathrm{CELtfp})\cdot(1-\mathrm{CESCtfp}-\mathrm{CELnufp})} + \frac{\mathrm{at,l} \cdot \mathrm{CAPEX} \cdot \mathrm{OPEX}}{\mathrm{LF} \cdot \mathrm{IPT} \cdot (1-\mathrm{CESCtfp}-\mathrm{CELnufp})}$ [EUR.MWh^{-1}] (9)

where BP is the price of biomass expressed as price of heat in fuel [EUR.GJ^{-1}], at,l is the annuity factor for given physical lifetime of a specific conversion technology and for a given rate of return [%], CAPEX is the investment cost of a particular conversion technology [EUR], OPEX is the annual operation cost of the mentioned conversion technology [EUR], LF is the load factor of total installed capacity in electricity and heat [hours] and IPT is the total installed capacity in electricity and heat [kW].

5. Results

Based on the allocation of forestry, conventional and energy crops in different land plots, respecting priority, and nutritional demand of the plants, it was possible to create, besides all other crops that were considered in the model, 8 scenarios of maize silage average yield (four scenarios per region, described in the methodology), which did not, significantly, vary among different scenarios. Considering the share of energy crops in agricultural land, in Strakonice it was increased from 0%, in both distances in 2014, to 6,7% in a projection for 2050, in 10-50 km around the heating plant. In Hodonín, the increase was from 0,12% in 2014 for 10-50 km around the biogas plant to 5,9%, in 2050's projection. The following table details the input data for the application of energy and economic effectiveness:

Table 1 – Average yield based on allocation of crops in different land plots and share of energy crops in each situation. Source: Adapted from Deparment of Economics, Management and Humanities of Faculty of Electrical Engineering (CVUT Prague)

	2014		**2050**	
	yield	**share**	**yield**	**share**
Strakonice (0-10 km)	39.3	0.1%	39.3	5.8%
Strakonice (10-50 km)	39.1	0.0%	39.1	6.7%
Hodonín (0-10 km)	38.9	0.0%	38.2	5.8%
Hodonín (10-50 km)	40.6	0.1%	38.8	5.9%

The remaining data needed for the development of energy and economic effectiveness was based on the article published by the Department of Economics, Management and Humanities, regarding the Fuel Cycle Approach of these effectiveness evaluation of many types of biomass sources. As the following figure details:

Table 2 – Input data for energy effectiveness evaluation. Source: Knapek et al, 2015

Type of biomass and its use	**Yi [t/ha]**	**HVi [GJ/t]**	**CELts [GJ/GJ]**	**CELcip [GJ/GJ]**	**CELtfp [GJ/GJ]**	**CESCtfp [GJ/GJ]**	**CELnufp [GJ/GJ]**
Maize (biogas CHP)	40	5.4	0.1	0.33	0.15	0.15	0.35
Wheat (bioethanol)	5	16	0.01	-	0.49	0.35	0
SRC (direct burning, CHP)	24.4	6.9	0.1	-	0.2	0.05	0.1
Rape seed (FAME production)	3	23.9	0.01	-	0.42	0.45	0
Maize (biomethane)	40	5.4	0.1	0.33	0.08	0.25	0

Reed Canary Grass (spring harvest, direct burning, CHP)	10	12	0.1	-	0.2	0.05	0.1

Other data were surveyed to continue with the effectiveness approach. The heating value, for example, was considered 4.5 $GJ.t^{-1}$, instead of what is shown in the above image. Other, not shown in the previous table, was available in the same article. For instance, energy consumption for biomass transportation (average maximum distance 50 km) was considered 2 $GJ.ha^{-1}$, energy consumption for maize production, including harvest, was 15 $GJ.ha^{-1}$. In contrast, the energy consumption for biogas transportation was rejected, since it is directly used in cogeneration units or biogas stations to produce CHP or Biomethane.

With all necessary data for the whole evaluation, it was possible to describe the results of the energy effectiveness approach. On the following image, we have an example for biomethane production, per hectare, in 2050, around 10-50 km of the biogas plant in Hodonín (4th scenario):

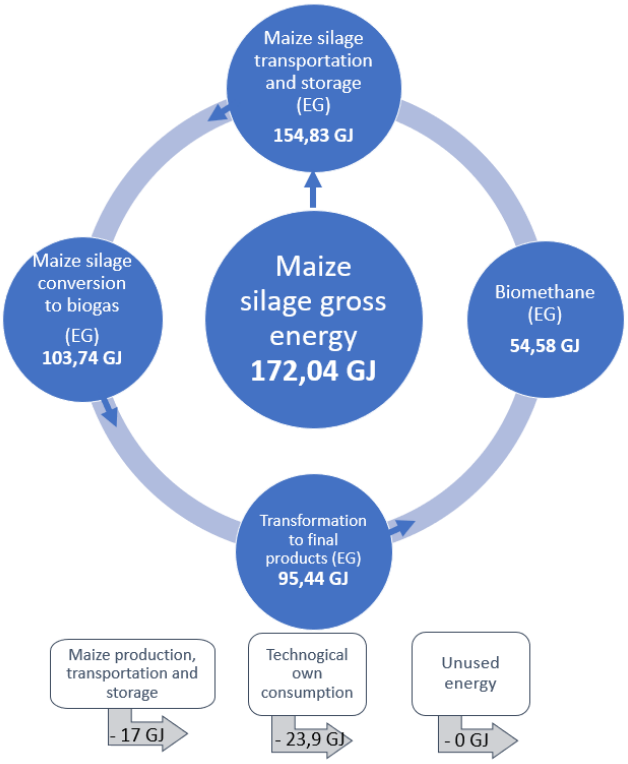

Figure 6. Energy effectiveness of biomethane for the fourth scenario of Hodonín case.

This example shows that the total net efficiency was 32%, from the gross energy content in maize silage to biomethane available to be injected into network grid. In contrast, it is possible to observe that the efficiency of CHP is lower, due to, mostly, the significant share of unused energy of heat that is lost when it presents difficultness to be competitive to long-distance consumers and when it is not sold to local demand after production. An example of

CHP production, per hectare, in Strakonice, 2050, of 10-50 km around the biogas plant, shows that the total net efficiency was 16%:

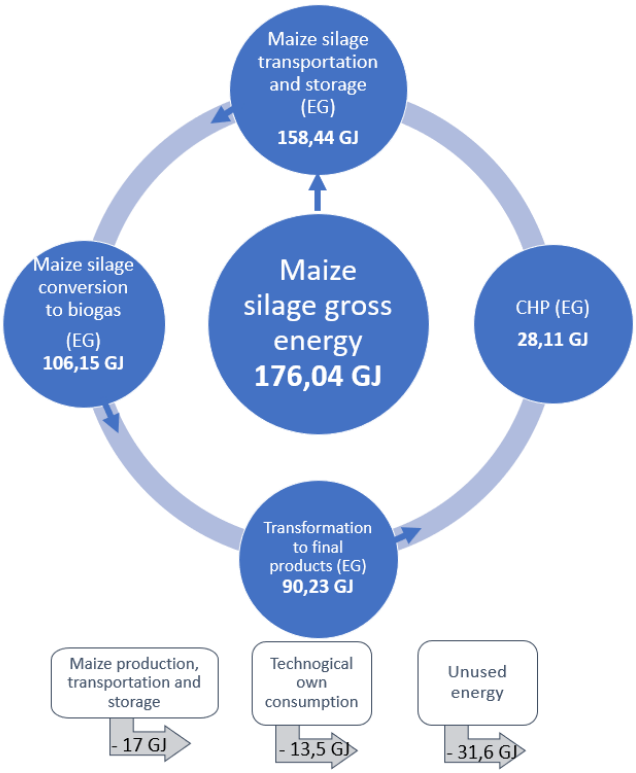

Figure 7. Energy effectiveness of CHP for the fourth scenario of Strakonice case.

It is important to highlight that these efficiencies are the same regardless the region or the distance from the biogas plant, since partial efficiency of each process came as percentage on the input calculation of the total net energy effectiveness for each scenario situation. Therefore, the efficiency previously mentioned is considered as general for each scenario, in each region. The summary of energy effectiveness approach is found in the next tables:

Table 3 – General efficiency for the production of:

Biomethane	32%
CHP	16%

Table 4 – Potential in GJ per hectare of each scenario situation:

Biomethane				
Scenario	**1**	**2**	**3**	**4**
Hodonín	55.83	59.02	55.65	54.58
Strakonice	56.50	56.22	56.50	56.24
Combined Heat and Power				
Scenario	**1**	**2**	**3**	**4**
Hodonín	27.86	29.82	27.75	27.09

Strakonice	28.27	28.10	28.27	28.11

Table 5 – Energy loss during production processes

Biomethane					
Scenario	**1**	**2**	**3**	**4**	(Avg %) **ȳ %**
Hodonín	77.94	81.35	77.74	76.60	45%
Strakonice	78.65	78.35	78.65	78.38	
Combined Heat and Power					
Scenario	**1**	**2**	**3**	**4**	**ȳ %**
Hodonín	85.33	89.06	85.11	83.86	49%
Strakonice	86.11	85.78	86.11	85.81	

Table 6 – Energy loss due to maize production, technological consumption, and non-usage issues

Biomethane					
Scenario	**1**	**2**	**3**	**4**	**ȳ %**
Hodonín	41.28	42.34	41.22	40.86	24%
Strakonice	41.50	41.41	41.50	41.41	
Combined Heat and Power					
Scenario	**1**	**2**	**3**	**4**	**ȳ %**
Hodonín	61.86	63.82	61.75	61.09	35%
Strakonice	62.27	62.10	62.27	62.11	

As mentioned previously, the economic effectiveness evaluation allows the comparison of different technologies used to manufacture end-use products of energy, even when they are produced from the same biomass. In directly words, it is possible to check, regarding production costs, whether is worth to purify biogas into biomethane instead of burning it in cogeneration units to produce heat and electricity, which is the main reality nowadays in the Czech Republic.

The costs of previously stages of the fuel cycle, that is, the production costs of raw maize silage, are reflected in its price at the entry of the biogas plant. Thus, it is assumed the market price of biomass input in the biogas plant, which for typical value in the Czech Republic is 6,56 EUR/GJ (assuming 10% of losses in the silage storage). The annuity factor (at,l) is calculated using the discount rate of 7% and 20 years of conversion/transformation technology lifetime, which is 9,44%. The specific investment cost and load factor (utilization of installed capacity in power and heat) are estimated at 2500 [EUR.kW^{-1}] and 7800 h, respectively. The total installed capacity (IPT) was considered as a unitary value of 1 MW and, consequently, the investment and operational costs will also be related to a unit of energy. Operational costs, as

maintenance, power consumption, manipulation with the silage, labor costs, etc., are estimated at 8,5% of invested capital for biogas upgrade into biomethane and 5,5% for CHP production. The values of coefficients CESCtfp and CELnufp will be the same as in the energy effectiveness evaluation.

The specific costs (SCPE – equation 10) calculation is divided into two components that can be calculated separately: firstly, the representation of the fuel costs transformed to the final product.

Then, the second part of the equation reflects the costs of conversion technology, which is separated between investment and operational costs. It's important to highlight that the economic approach does not depend on local factors that would result differently among the four scenarios mentioned in the methodology, therefore it only makes sense to analyze the economic effectiveness of the end-products, regardless the place of production. The results are shown in the following table:

Table 7 – Summary of economic effectiveness evaluation for each end-product considered in this study case [EUR.MWh^{-1}]

Cost type	Biomethane	CHP
Fuel costs (transformed to the final product)	51.1	82.9
Fixed costs (investments)	40.3	50.4
Fixed operating costs	36.3	45.4
Total	127.8	178.7

This study case shows that, in the conditions of the Czech Republic, biomethane is more effective than heat and power for a biogas plant, concerning its energy efficiency and production costs. It is also necessary to consider, in this approach, the market value for those commodities, which may impact directly in the profit of the business behind it. Besides, this methodology may be used as well to other crops and other transformation technologies used for different end-use energy products.

5.1 Discussion

In order to present a better discussion on biomethane and CHP as options for biogas plants, more information is needed to give a better background concerning the decision for the business behind biogas plants. Some available articles in the Faculty of Electrical Engineering of the Czech Technical University present an evaluation on biomethane usage, which may

strengthen the comparison of both commodities previously discussed. For instance, Jan Žákovec (2012) brings a discussion based on a SWOT analysis for biomethane. In his point of view, biomethane has an unquestionable advantage over electricity and heat, since it can be either injected into natural gas distribution network or compressed and used as BioCNG (compressed natural gas) in transportation and become a full replacement of natural gas, while heat and electricity present some problems due to the location of most biogas plants, which makes its losses becomes higher. According to Pavlíček (2016), the main advantage of biomethane is its flexibility, as it can be used for the same spectrum of technical applications as natural gas. In addition, additional investments related to the pipeline network are not created, as the existing natural gas network (subject to qualitative requirements) can be used, so biomethane is very easy to store. The following image shows a brief SWOT analysis, based on Žákovec's thesis.

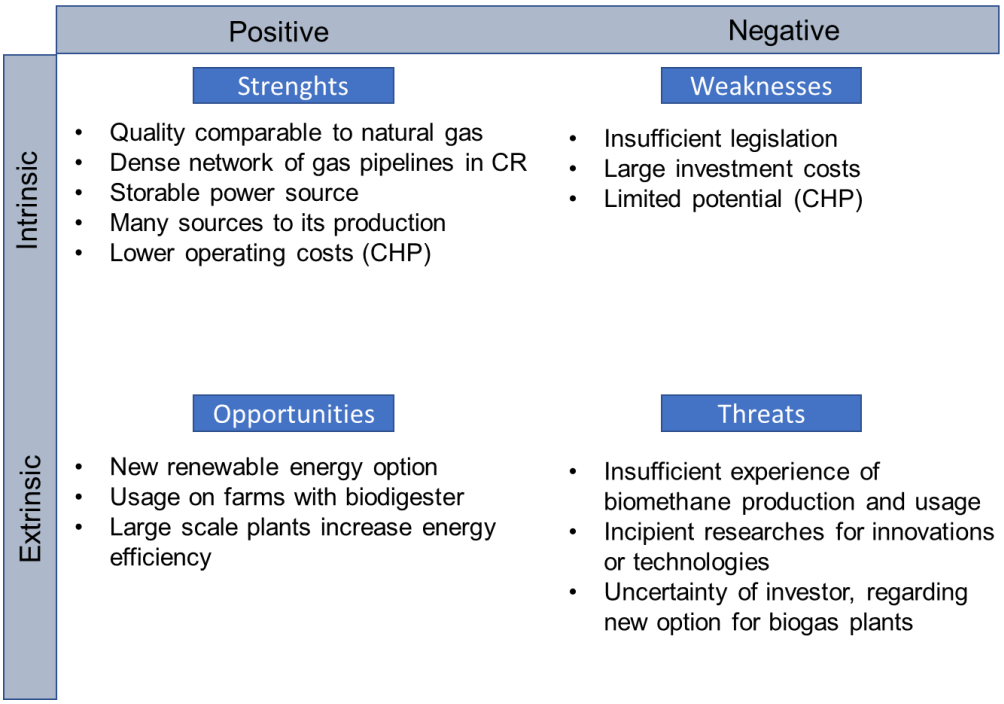

Figure 8. SWOT analysis on biomethane in the Czech Republic. Adapted from Žákovec (2012)

In contrast with Europe examples, Brazil has a huge territory and vast potential to develop its biogas complex and, possibly, explore biomethane as a fuel. D'aquino (2018) showed that, in the country, this sector is still in development, since it has been only one year that biomethane has been regulated as vehicle fuel from landfills and water treatment stations. Besides, biogas presents the potential to cover almost one fourth of national demand of electricity and, still, the country does not present as many biogas plants as european nations. Fortunately, there are success cases of biogas plants and biomethane production around the country, located in states as São Paulo, Paraná, Rio de Janeiro, Ceará, etc.

6. Conclusions

This study case gives fundamental information to develop a strategic energy crop cultivation policy in the Czech Republic, since the country presents agricultural and arable land as a limited factor to food and energy (from biomass) supply. In order to reach EU demand of increasing the share of RES in energy supply, the share of energy crops in arable land in the Czech Republic will, naturally, increase. So, it is applicable to Czech government to create a policy that support biomass development (also from agriculture and forestry) and still defend food supply in the country. An interesting tool that should help this effort is the exploration and support of projects and researches of this nature, considering different scenarios of crops allocation, in order to find the best way to achieve mid and long-term goals

Considering end-use products, nowadays, in the Czech Republic, almost all biogas plants tend to use this input in cogeneration units for heat and electricity purposes. Such use of biogas has been proven in this study, and many others, that present some disadvantages, regarding its comparison to biogas upgrade into biomethane, where most of them are related to higher level of energy losses during production processes. This choice, from responsible people of biogas business, might be associated with local demand and, an important factor, government support for CHP sector, which is not as much frequent as in biomethane scene.

Biogas treatment for biomethane, either for gas injection in natural gas grid or motor vehicle propulsion, represents a much more efficient way of using this input, with the possibility of storing the energy content of it. Currently, the main barriers for its development in the Czech Republic are the lack of legislation and no support from the government and its dependence on natural gas to be developed in transportation sector, which presents an insufficient network to provide fuels to CNG filling stations, besides on the modest usage of CNG vehicles in the country.

Since Brazil's situation on biogas complex is still growing, it would be clever to get closer to Europe's experience. An expertise on the main advantages and drawbacks and on the market itself of biogas complex would give strength to Brazilian (as much as possible) clean energy development.

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