TE-O-06 Planning the sustainable use of agricultural bioresources as fuel for city busses: example case Turku, Finland

S. Rasi, E. Lehtonen, P. Kässi, A. Seppälä
Natural Resources Institute Finland, Tietotie 2C, FI-31600 Jokioinen, Finland
saija.rasi@luke.fi

1. Objectives

Transport produces about 20% of Finland's greenhouse gas emissions. Transport is the second largest CO_2 emitter following the electricity and heat production emissions. Although Finland has invested heavily in biofuels in heat and power production and the share of renewable in energy production is 36.8% (in 2013), the share of petroleum products in transport is still about 90%. Many studies have concluded that biomethane is one of the most sustainable biofuels available today [1]. Biomethane is a gaseous fuel, which is produced from biogas and as well as natural gas, it can be used as vehicle fuel in different types of vehicles. The sustainability of biomethane is partly because biogas can employ various types of waste materials as feedstock and when biomethane is produced from energy crops, the residual from the process can be used as fertilizers, thus minimizing the use of inorganic fertilizers. The air emissions from the use of gaseous fuels in vehicles are also lower than from liquid fuels, because of the higher ignition temperature and a higher lower flammability limit than liquid fuels [2].Feedstock availability, the most critical requirement for biomethane promotion, is linked to systematic analysis and planning the sustainable use of regional biomass resources. In many cases the theoretical biomasses potential for bioenergy production may be large, nevertheless a detailed analysis of land availability and the infrastructure may limit the actual amount of potential biomass to half of the theoretical amount [3].

The role of financial supports, both national and EU funded, that control the use of fertilizers and agricultural land is essential when planning the biogas production from field biomasses. Well managed biogas production from field biomasses can sustain fertility of the fields by closing the nutrient cycles. However, the harvested phosphorus yield may exceed the allowed phosphorus fertilization when field phosphorus level is good or high under the terms of Environmental support of Agriculture in Finland [4]. Under previous years (2007-2013) 95% of the field area [5] used in the Finnish Agricultural production was run according those terms, implying importance of those restrictions. Thus the area needed for spreading digestate may exceed the area needed for biomass production additionally the digestate may be needed to be processed to some extend to separate the main nutrients (P and N) from each other. Further some additional nitrogen fertilization may be needed for good biomass yield [6].

Logistics and storage play important role in economics of biogas production and their role is pronounced in Finland where spreading of digestate is not allowed in wet soil or during winter (from November to March) [7] and wet soil is restricting the spreading typically some periods each year. Transportation costs of digestate may easily exceed the respective value of digestate nutrient content [6]. Further, the effects of logistics on the local traffic and dwellings should be taken into account.

The objective of the research was to plan sustainable biomethane production from energy crops for city busses in Turku. The aim was to assess how much fields are needed and how digestate can be used as fertilizer in sustainable way in surrounding areas. The objective was that the biogas plant and fields in surrounding area form a closed cycle of nutrients and that this example case brings tools for future biogas plant planning.

2. Case study description

In Turku, about 3 Mm^3 of biomethane is produced per year from waste materials. Needed amount of methane for city busses in the area is about 5.6 Mm^3. Basis for the study was that extra 2.6 Mm^3 of methane could be produced from energy crops. The potential location of new biogas plant (Topinoja area) was selected as a request of Turku city, as there is an existing biogas plant processing biowaste and sludge in the same area and the area is logistically potential area for biomethane distribution. The area (Fig 1) is between rural and urban area. Grass was selected as raw material as methane potential of ensiled grass is good, years of crop failure are rare and production costs compared to energy content of product are reasonable. Also, cultivation, harvest and preservation of grass are known and all technical solutions are available (compared to e.g. maize production in Nordic countries) [8]. The needed amount of field for grass cultivation and nutrient recycling was based on two alternative scenarios. In base case only grass species were cultivated requiring strong nitrogen fertilization. In alternative case, cultivation was partly based on a mixture of grass and clover that is able to fix nitrogen from atmosphere. Mixture was cultivated on the fields where spreading digestate is not allowed due to the high phosphorus status of the field, where cultivation of clover would enable harvesting relatively good yields without fertilization. It was assumed that cultivation will follow EU nitrate regulation [9] and terms of Environmental Support of Agriculture 2014 [4] (e.g. taking phosphorus status of the field in Turku area into account). It was also assumed that nutrients from biogas digestate will be recycled back to fields and the inevitable nitrogen loss will be replaced with chemical fertilizers used on grass fields. Soluble nitrogen and water soluble phosphorus of digestate were taken into account when calculating the amount of nutrients that should be returned on to the fields. Solubility of nitrogen and phosphorus in digestate were assumed to be 65% and 85%, respectively. The field phosphorus level was calculated from statistics of soil samples [10].

For field location information and distance calculations, geographic information system (GIS) was used. Fields over 1.5 hectares were taken into account. Transportation distances were derived using the OD Cost Matrix application in ArcGIS Network Analyst which uses the Dijkstra's algorithm in order to determine the shortest path from a starting point to a destination location. The criteria for storage locations were good roads between Topinoja and storages, large field density and low population density between storage areas.

3. Observations

In was assumed that the harvested 7500 t dry matter (DM) grass/ ha would remove 22 kg/ha phosphorus and the yield (5625 t DM /ha) of clover –grass mixture would remove 13 kg/ha phosphorus. The phosphorus amounts are above the maximum allowed yearly phosphorus fertilization of the grass fields according to the terms of Environmental support of Agriculture in Finland 2012, assumed that the field has phosphorus status at least satisfactory/tolerable. Phosphorus status of the fields of the study area was satisfactory/good, meaning that part of the digestate should be used for fertilizing something else than grass for biogas production. Further, it was taken into account that the pure grass species require nitrogen fertilization despite the phosphorus status of the fields. When calculating the field area needed for sustainable raw material production for biogas plant, the factors taken into account included the phosphorus status of the fields, crop yield, amount of harvested nutrients and allowed fertilization of grass and nurse crop of establishment year.

The needed grass area for producing 2.6 Mm^3 methane is from 1100 to 1300 ha depending on the proportion of clover in the grass mixture (Table 1). High grass yield is achieved by the pure grass species if additional source of nitrogen fertilization is used (in addition to the digestate 87 kg nitrogen/ha grass). Area needed for grass re-establishment is from 280 to 350 ha yearly, barley would be cultivated as nurse crop. Additionally, some phosphorus surplus (2 kg/ha) will be establish in the case of pure grass species, meaning that additionally over 200 ha grain area will be fertilized with the digestate. Further approximately 10 % safety margin was suggested to cover the yearly variation in the yields. Thus regardless of the composition of grass sward 1800 hectares would be needed to operate nutrient cycle and biomass production of the biogas plant.

The needed 1800 ha area can be obtained within 9 km radius from Topinoja biogas plants if presumed that all field plots above 1.5 ha in size are available for biomass production (Fig 1). With increasing distance, the field area increases rapidly enabling energy crop cultivation along with food and feed cultivation. If 20 % of the farmers of surrounding area are producing grass for biomethane production and/or using digestate to fertilize their fields, the needed 1800 hectare field would be located less than 15.4 km radius from biogas plant.

Quite often silage and sludge transportation is done by tractors when the distance is less than 10 km. However, Topinoja area is located near big roads so tractor transportation would have a negative effect on local traffic. Using temporary storages would enable truck transportation and possibility to choose the time for transportation, e.g. avoiding rush hours.

Table 1: Calculated field area needed for running sustainable biogas production to produce 2.6. Mm^3 biomethane. Two alternative scenarios compared.

	Red clover included*	Without clover**
Methane production m^3/kg DM	0.30	0.31
Harvest kg DM/ha	6 769	7 500
Nitrogen yield kg/ha	184	180
Phosphorus yield kg/ha	18	22
Methane production m^3/kg ha	2 068	2 355
Needed grass field area, ha	1 257	1 104
Area for grass sward establishment, ha	348	276
Additional area needed for digestate nutrients recycling	0	213
Total amount of field, ha	1 605	1 593

* Mixture of red clover and grass species (typically timothy and meadow fescue) cultivated on the fields having good or high phosphorus level (39 % of the field area, phosphorus class above satisfactory).

** Only grass species (timothy, meadow fescue etc.) cultivated and additional nitrogen fertilization included

DM = dry matter

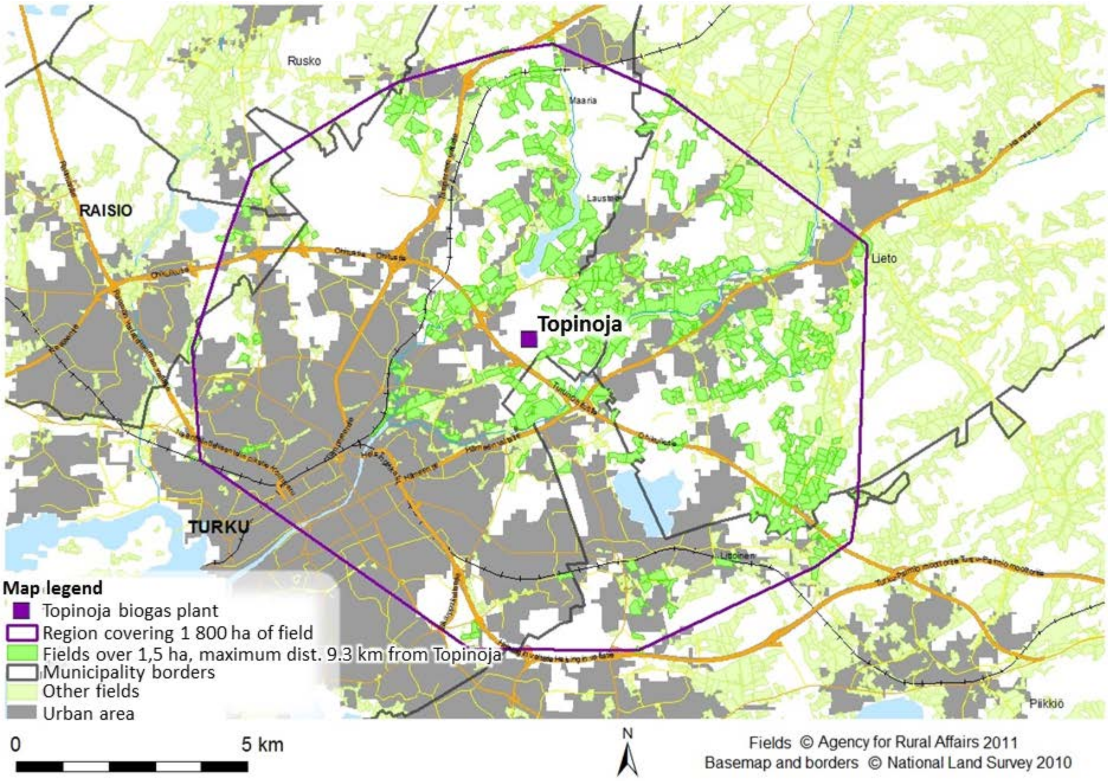

Figure 1: The needed 1800 ha fields close to Topinoja area (distance max 9.3 km along roads).

Due to traffic reasons, the temporary storages were suggested during this project, both to grass silage and to digestate. Amount of fields near selected storage areas is about 9 000 ha. This area is big enough to produce the needed amount of energy crops if at least 20% of fields in the area are producing energy crops. If all the field close to storage area are used for energy crop cultivation, the needed transportation distance from field to storage is on average 2.5 km. If about 33% of fields in the area are used for energy crop cultivation, the transportation distance will increase to about 4.6 km. With 20% filed, the transportation distance is in average 6 km.

The economics of the biomethane production is depended on the distance from fields to the biogas plant but also the price of oil and the alternative crop, e.g. barley. The price of biomass will increase if the distance to biogas plant is increasing (Fig 2). The price includes compensation to farmers of the field use, the price of harvest and transportation and the price of nutrients (including spreading of fertilizers and digestate, digestate transportation and profits of selling nutrients). The high cereal price increases also the prize of energy crops as alternative use of fields is more tempting for the farmers.

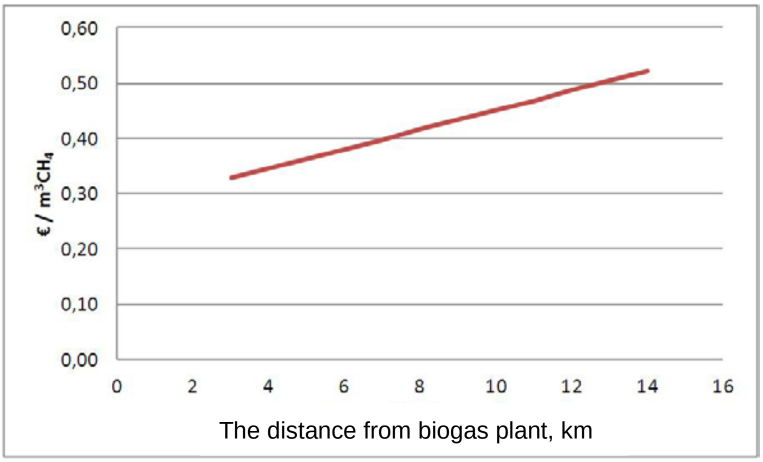

Figure 2: The price of biomass is depended on the distance from the biogas plant.

In previous studies, it was calculated that the biomethane production is more profitable when all the produced gas can be sold for transportation use as gaining profit from electricity or heat is more difficult in Finland [11]. In this case, the amount of produced biomethane is based on the need of local bus transportation if they were using biomethane as a fuel. However, at the moment, city of Turku has not made the decision to change all local bus transportation running on biomethane.

4. Conclusion

When planning a biogas plant which utilizes field biomasses, the amount of nutrients in digestate and the allowed/needed fertilization of the crops should be taken into account in order to obtain closed nutrient cycle. In Turku case, the needed field area for digestate distribution is larger than the area needed for biomass production. In conclusion, 2.6 Mm^3 of biomethane can be produced on the target area based on closed nutrient cycle and grass silage as raw material and the bioenergy production can be done along with food and feed production. In generally, crop and fertilization planning is in crucial role when planning a biogas production from field biomasses and should be done prior to the investment decision. The total economics of the biogas plant could also increase, if the digestate was processed to more valuable fertilizer product, reminding more chemical fertiliser and thus being more familiar for farmers. Although, for that, more advanced digestate treatments technologies are needed.

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