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Economic viability and geographic distribution of centralized biogas plants: case study Croatia

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Abstract Current promising increase of agricultural investments in Croatia not only leads us to the implementation of new technologies and procedures but also leads to an increase of public awareness toward modern agricultural production. As a side effect, renewable energy sources, with special emphasis on biogas, are quickly coming under the loop. Because of this effect, a question of total biogas potential for the farming sector in Croatia becomes very important. One of the biggest obstacles in utilizing biogas on Croatian farms is its geographical displacement and small size. Through this paper economic viability and geographical distribution, as key parameters in determining realistic biogas potential on family farms, will be presented with special emphasis on the two most promising farming sectors: cows and pigs. As already mentioned, one of the biggest barriers in utilizing biogas in Croatia is the relatively small size of farms that are not capable of having economically viable biogas production. That is why community biogas plants will be important in increasing biogas utilization in Croatian farming sector. Presented methodology represents basics for regional analysis of biogas potential of a farming sector with Croatia as a case study with cost assessment of community biogas power plants considering transport distances, transport costs, and size of the power plants and family farms involved in community biogas production. The value of finding Croatia's farming biogas potential is also important since farms are high-volume energy consumers in their everyday operations and part of that energy consumption can be compensated from renewable energy sources like biogas.

Keywords Centralized biogas plant · Renewable energy sources · Croatia · Economic viability · Geographic distribution

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Introduction

Farming sector, in general, is a large producer of manure (Jaber et al. 2004; Svensson et al. 2006; Uddin et al. 2010) and thereby also a large producer of greenhouse gases (Fan et al. 2007; Bauer et al. 2010). Methane production from animals on farms should be seen as an opportunity in utilizing green and sustainable energy (Ucekaj et al. 2010; Dikshit and Chakraborty 2006) which would contribute to the reduction of green house effect. We can say that Croatian farming sector is still pretty under developed if we compare it to the other EU member states (Bauer et al. 2010; Steininger and Voraberger 2003). This is one of the legacies from the past state where agriculture was not something worth heavy investments. This was not only the case for Croatian farming sector, but also for Croatian agriculture in general for the last twenty or more years. However, in the last 5 years, there were a lot of improvements and investments in agriculture and in the farming sector. More and more questions regarding energy issues and energy management on farms are becoming important (Schaffner et al. 2010; Kongsil et al. 2010). However, this is still not enough if we want to use all the available resources and potentials. The number of serious biogas plants in Croatia's agriculture sector is still negligible, which shows the underdevelopment of biogas utilization. Modern agricultural production demands new approaches regarding cost reduction, modernization and greenhouse

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gas control (Lund 2006). With the increase in fossil fuel prices, energy efficiency and renewable energy sources are becoming crucial aspects in economically viable agricultural production (Schneider et al. 2007; Krajačić et al. 2011; Fowler et al. 2009). Biogas possibilities in agricultural sector is the most logical choice when addressing energy production, both thermal and electrical, greenhouse gas reductions and manure management (Al-Ghazawi and Abdulla 2008; Kameswari et al. 2011; Schausberger et al. 2010).

In a previous research (Pukšec and Duic 2010) basic methodology regarding technical biogas potentials in Croatian farming sectors have been shown. One of the focuses of that study was the potentials of large Croatian farms and family farms regarding their technical biogas potential. One of the main shortcomings of that research was the lack of understanding of the possibilities of tapping biogas potential from Croatian family farms. The present situation is characterized with a lot of small family farms which do not present economically viable biogas producers. These kinds of farms do not have significant biogas potential and basically present waste of energy regarding biogas production. Biogas potential of family farms is interesting information since it tells us how much energy is dissipated and lost because of the inefficient agricultural system. This total technical potential is significant and presents a respectable amount of renewable energy that stays unused. In Table 1, this unused potential of Croatian family farms, breeding cows is shown. Also, similar potential calculated based on small family farms, breeding pigs is shown in Table 2.

Through this paper, mechanisms necessary to utilize some of the biogas potentials coming from Croatian family farms will be discussed. Community digesters are the most logical solution in utilizing biogas potential from Croatian farming sector, not only allowing farmers to manage their manure but also allowing them, through participating in centralized community biogas plants, to earn an extra profit for their farms (Lin et al. 2009; Taal et al. 2003; Hjort-Gregersen 1999). Main focus of this paper will be on family farms whose main activity is cow and pig production. A few of the key parameters influencing in viability of community biogas digesters in Croatia will be the distances between farms and digesters, feed in tariffs, and manure prices. Two main approaches considering ownership status will be presented. First option to be presented is the third-party ownership where farmers do not own any centralized biogas plant but just sell their manure to the biogas plant. This option does not present the most probable one, but, nevertheless, it is one of the possible future options especially in the respect of the new EU directives regarding manure management where farmers will need to consider new forms of manure management. And with Croatia soon to become an EU member state, this question becomes more real. An other option analyzed through this paper is the situation when farmers jointly take over the ownership of the biogas plant and they start feeding the biogas plant with manure they produce on their farms.

Table 1 Family enterprises, breeding cows and their biogas potential (Pukšec and Duic 2010)

	Number of breeders	Number of cows	Average (cow/breeder)	Biogas potential (kW)	Available heat (kW)
Total	23,053	167,866	7.28	26,001	45,616

Table 2 Family enterprises, breeding pigs and their biogas potential (Pukšec and Duic 2010)

	Number of pigs	Biogas potential (kW)	Available heat (kW)
Total	1,726,895	22,771	39,950

Methodology

Two main approaches have been analyzed when calculating economic viability and geographical distribution of centralized biogas plants. Third-party ownership presents an easier way out for farmers since they themselves do not need to deal with investments and operating the biogas plant; they just participate through selling the manure and collecting the processed substrates. On the other hand, the situation where farmers taking over the ownership of centralized biogas plant presents not only potentially higher revenues but also higher financial responsibility.

Third-party ownership

It is important to show how farmers can benefit from centralized biogas plants. The first option is to sell their manure to centralized biogas plants operated by third-party and that way earn extra profits and manage their manure in the best possible way. First, dependences between biogas plant size and profitability, in the Case of Croatia, will be shown. One of the first parameters influencing biogas plants profitability will be the feed in tariff (Cosic et al. 2011). Through the "Results" section these dependencies will be presented and commented in a more detailed way. Yearly net earnings are presented as

$$N_E = FIT\left(\frac{BE\eta_{CHP}}{1+R_{el/heat}}A\right) \quad (1)$$

where N_E, yearly net earnings (€); *FIT*, feed in tariff (€/kWh); *B*, yearly biogas production (m^3/h); *E*, energy value of biogas (kWh/m^3); η_{CHP}, CHP efficiency; *A*, availability (h/year) and $R_{el/heat}$, CHP electrical energy/heat ratio.

Based on the profitability of a biogas size plant, the maximum manure price at the plant (Pipatmanomai et al. 2009), which would allow a positive balance, could be determined:

$$P_{PP} = \frac{\left(FIT\left(\frac{BE\eta_{CHP}}{1+R_{el/heat}}A\right)\right) - (C_I + C_{O\&M})}{M_a} \quad (2)$$

where P_{PP}, maximum price of manure at the biogas power plant (€/t); C_I, investment cost (€); $C_{O\&M}$, operation cost (€) and M_a, yearly manure input of biogas power plant (*t*).

Through the maximum price of manure at the biogas power plant, possible price that a third-party owner would pay for a positive plant operation can be seen. Next step would be to calculate what would be the price of manure that could be paid to the farmers. Of course, transportation cost would play an important role in determining the final buying price that a third-party owner can pay to the farmers. Price of manure that the farmers could sell to centralized biogas power plants was calculated through

$$P_F = \left(\frac{P_{PP}M_F}{M_a} - (SD)\right) \quad (3)$$

Where P_F, maximum price of manure on the farm (€/t); M_F, yearly manure production of a farm (€/t); *S*, specific cost of manure transportation (€/t/km) (Yagüe et al. 2008) and *D*, distance between the farms and centralized biogas power plant (km).

Transportation cost plays an important role in determining the final manure price on the farm. In the presented analyses, only truck manure transportation was considered. Possible pipeline transportation for shorter distances could also be considered in future calculations.

Farmers own ownership

The second option is when farmers take over the ownership of the centralized biogas plant. In this situation farmers need to take over all of the investment as well as operating costs of the plant. If farmers are taking over the risk of success then the most important parameter would be the profitability of the plant and the possible payback period. One of the possibilities of expressing the profitability of a certain plant could be presented through the following equation

$$R_{pp} = \frac{FIT\left(\frac{BE\eta_{CHP}}{1+R_{el/heat}}A\right)}{(C_I + C_{O\&M})} \quad (4)$$

where R_{pp}, biogas plant profitability index.

In order to calculate costs, both investment and maintenance, for farmers sharing the ownership of the biogas plant specific investment and maintenance costs needs to be expressed:

$$Ki = \frac{C_I}{M_a} \quad (5)$$

where *Ki*, specific investment cost (€/t).

$$Km = \frac{C_{O\&M}}{M_a} \quad (6)$$

where *Km*, specific operating and maintenance cost (€/t).

Farmers will need to invest for initial investment, and operating and maintenance costs depending on their farm size:

$$Ri = KiMt \quad (7)$$

where *Ri,* investment cost for a farmer (€) and *Mt*, farm size participating in the centralized biogas plant (t/year).

$$Ro = KmMt \quad (8)$$

where *Ro*, yearly operating and maintenance cost for a farmer (€).

Results

One of the key elements regarding the profitability of a biogas plant in Croatia, as well as in other EU countries, is the feed in tariff (Walla and Schneeberger 2008). In order to examine this dependence, this paper gives comparison of different basic net earnings and the profitabilities compared for different feed in tariffs which are calculated for various biogas plant sizes. Table 3 presents benchmark values used to compare different economic viabilities for different feed

Table 3 Data used for Feed in tariff comparison

Yearly manure production (*t*)	Yearly biogas production (m^3)
4,390	98,800
7,200	161,970
14,400	323,940
28,800	647,880
43,200	971,830
57,600	1,295,770
72,000	1,619,710
86,400	1,943,650
100,800	2,267,600
100,800	2,267,600

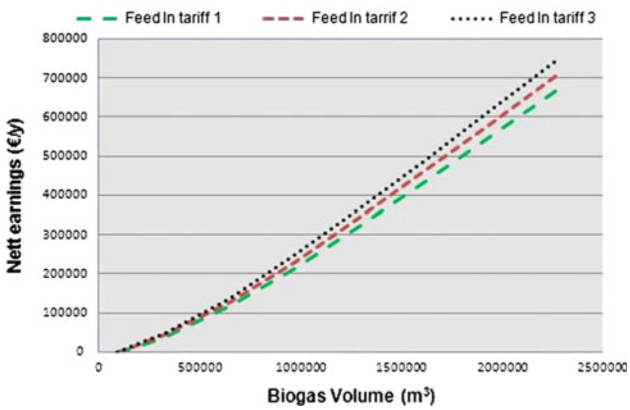

Fig. 1 Biogas production and net earnings ratio for Feed in tariff 1 (1.2 HRK), Feed in tariff 2 (1.25 HRK), and Feed in tariff 3 (1.3 HRK)

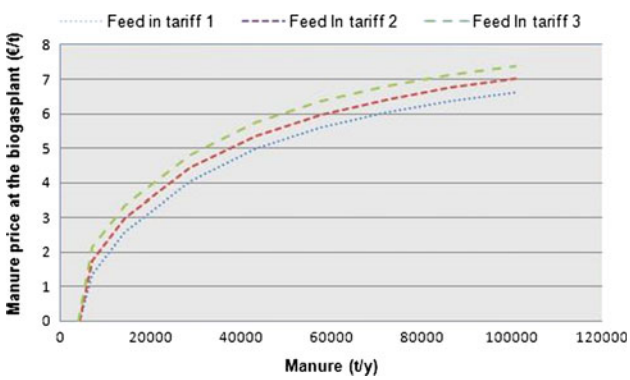

Fig. 2 Maximum manure price at the biogas plant

in tariffs. Each of the yearly manure production as well as biogas production in Table 3 presents a biogas plant size. These values are used to determine the influences of further feed in tariff, which are presented on Figs. 1, 2 and 5. The presented results are connected to manure prices, investment, and operating costs, with the main focus being on two reference biogas plant sizes: 500 kWe and 1 MWe.

Third-party ownership

Results of this research are presented for centralized biogas digesters up to 1 MWe, and are calculated with the feed in tariffs for Croatia of 1.2 HRK (0.1632 €). As already mentioned, any kind of increase in feed in tariffs would substantially influence the future earning of a biogas plant as well as its profitability and economic viability. Even a small increase in feed in tariffs leads to significant increase in the profitability, making this component very important when discussing centralized biogas plants (Fig. 1). As can be concluded from Fig. 1 the increase in feed in tariff would be more expressed in the case of bigger biogas plants making bigger biogas plant's more sensitive regarding fluctuations in feed in tariffs. Based on Fig. 1, it can be concluded that Feed in tariff 3 would allow 12% higher yearly net earnings than the referent Feed in tariff 1 which is currently valid in Croatia.

Feed in tariff 1 as a referent one regarding this calculation is set based on Croatian energy regulation which states that all biogas plants under 1 MWe fall under 1.2 HRK, per kWh of produced electricity. Feed in tariff 2 in this calculation is set as a possible value of 1.25 HRK while Feed in tariff 3 is set on 1.3 HRK. With an idea of a third-party ownership, farmers would sell their manure to biogas plants. Based on the literature and on-field experience, we are witnessing this option regarding other types of biomaterial used as a fermenter's feed, such as crops or industrial waste. That is why selling manure is a probable option in the future. From Fig. 2, the influence of biogas plant's size is visible. Increase of the biogas plants' size is the key factor in determining the manure price at the biogas plant location. Feed in tariff is also an important factor in determining the manure prices at biogas plant, but not as predominant as the biogas plants' size. Based on the suggested model, the maximum manure price at the biogas plant location can go up to 7 €/t for the larger-sized biogas plants, in this case, 1 MWe.

Based on the previous research (White et al. 2011), comparisons regarding net earnings and operating costs could be made. Net earnings of a biogas plant, using cattle manure, with 220,000 m^3 of biogas per a year, would yield a difference of 3.5% if we compare it with the results presented in this paper. The most obvious reason for this would be the similarity between Croatian and Canadian feed in tariffs. The price of manure that the farmers can sell to a third-party owner of a centralized biogas plant depends on a few factors: the size of the centralized biogas plant, the distance of a farm from the centralized biogas plant, and the size of the farm. In Fig. 3, dependences of the manure price on the farm and size of the farm can be seen.

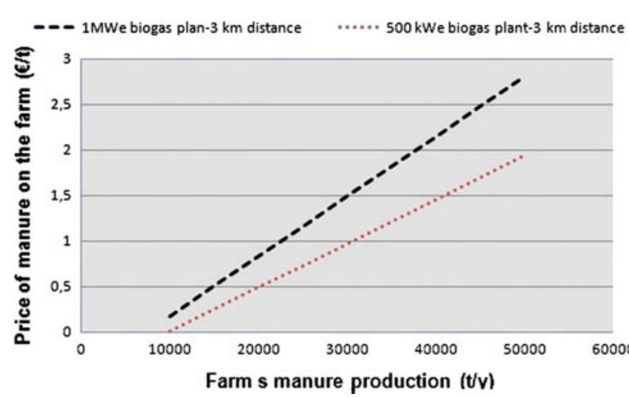

Fig. 3 Maximum manure price on farm's location dependending on the farm's manure production

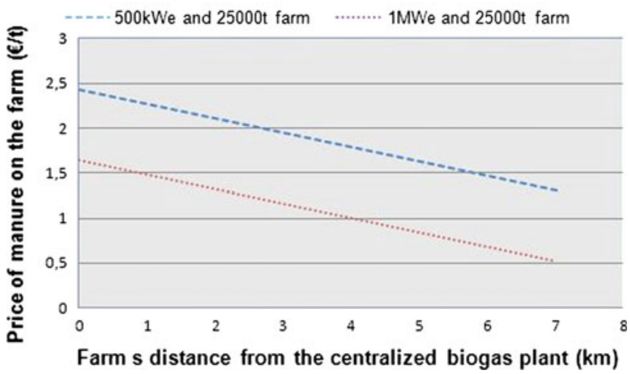

Fig. 4 Maximum manure price on farm's location depending on farm's distance from centralized biogas digester

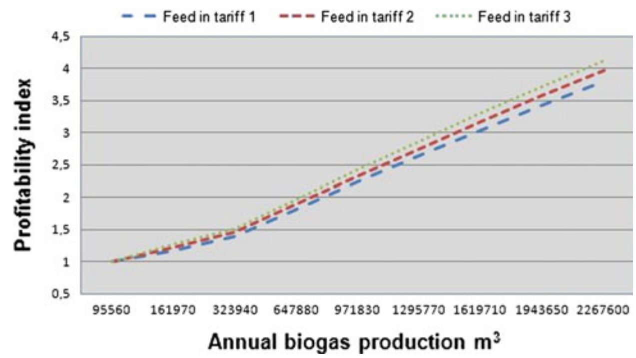

Fig. 5 Profitability index of a biogas plant depending on the size and feed in tariff

Manure selling prices for farmers whose farms are 3 km in distance from the centralized biogas plant are presented for two biogas plant sizes: 500 kWe, and 1 MWe. As seen from Fig. 3, larger farms selling their manure to the centralized biogas plants of 500 kWel would gain higher manure prices than smaller farms. The same scenario is visible for farms selling their manure to bigger centralized biogas plants of 1 MWel with one addition. The increase in manure prices due to farm's location would be steeper for bigger centralized biogas plant. Based on Figs. 3 and 4, bigger farms supplying bigger centralized biogas plants would be the optimal solution.

One of the main assumptions, proven on Fig. 4, is the decrease in the manure price due to farm's location based on the increase of the farm's distance from the centralized biogas plant. Difference between manure prices for two referent centralized biogas plant sizes is proven to be constant with the increase of the distance between farms and the centralized biogas plant. Transportation cost is one of the key issues when it comes to the profitability (Lindboe 1995). In this case, current market value of the manure will dictate transportation distances and based on available case studies (Flotats et al. 2009), these distances are in a range between 3.8 and 5.6 km, which matches the range of the centralized biogas plant presented in this paper.

From this research, it is clear that the price of the manure from farms that are further than 10 km from centralized biogas plant up to 1 MWe are just not viable for a third-party owner as well as for a farmer selling the manure. These data correlate well with the methodology already used (Dagnall et al. 2000) when investigating biogas options based on cattle and pig manure.

Farmers own ownership

In order to start planning centralized biogas plant owned by farmers who are at the same time supplying the plant with manure, determining the plant's profitability would be the first step. As already analyzed in the previous paragraph, feed in tariffs are proven to be a considerable factor in determining the profitability of the biogas plant. In Fig. 5, the profitability indexes for different feed in tariffs and biogas plants are shown. Based on the increase of profitability with the increase of feed in tariff, this would be a valid negotiation position for all future investors and policy makers.

It would also be interesting to see how nonmarket cobenefits could influence the economic feasibility of a centralized biogas plant. Most important nonmarket cobenefits would include odor control and reduction, pathogen reduction, GHG emission reduction, as well as water contamination reduction (Yiridoe et al. 2009). Further analysis in this direction would give much more information on the economic viability of centralized biogas plants, especially in the light of future legal regulations regarding manure management.

Also one of the conclusions that could be drawn from Fig. 5 is that higher feed in tariff allows farmers to retain the same profitability index with the smaller biogas plant sizes.

Two benchmark biogas plant sizes are shown when analyzing investment cost that the farmers would need to cover, 500 kWe and 1 MWe biogas plants (Fig. 6). Smaller biogas plant means less potential contributors as well as increased risk sharing since fewer farmers could be involved in the project. With a bigger biogas plant, specific investment cost that every farmer would need to cover would be smaller allowing more farmers to join in at a cheaper rate. Of course more potential participants in the centralized biogas plant would mean more work when it comes to the management issues. The same situation is with maintenance and operating costs for farmers (Fig. 7). With bigger biogas plant more farmers could join in allowing lower operation and maintenance costs. It is also important to stress that more owners also means more hassle regarding operation and decision making. When analyzing operation and maintenance costs one of the conclusions drawn from Fig. 7 is that bigger biogas plants

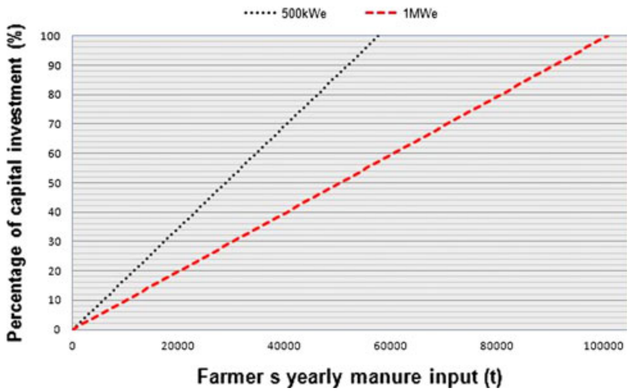

Fig. 6 Capital investment cost ratio compared with farmer's yearly manure input

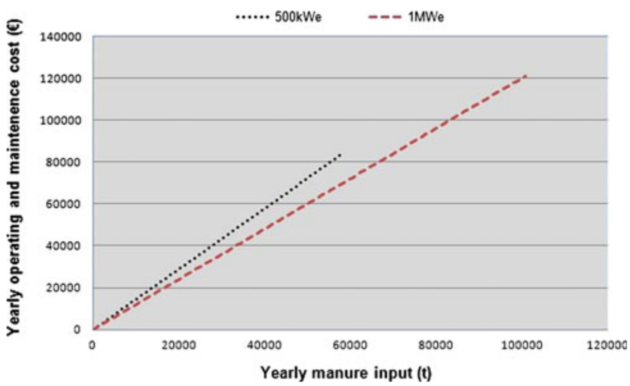

Fig. 7 Yearly operating and maintenance costs depending on the farmer s farm size

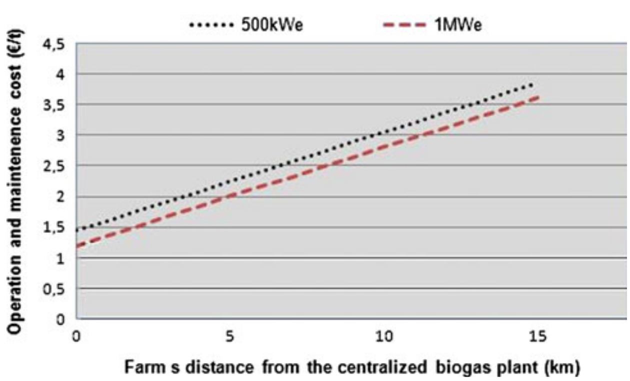

Fig. 8 Influence on operating and maintenance cost based on farmers farm distance from the centralized biogas plant

would mean lower specific costs for farmers participating in the centralized biogas plant.

Farm participating in a joint biogas plant needs to be as close as possible to the centralized biogas plant since transportation cost heavily influences the operation and maintenance specific cost (Fig. 8). Increase in maintenance and operating cost also has an impact on the profitability of the centralized biogas plant and the earnings of farmers participating in the venture. Based on Fig. 8 maintenance and operation costs after 15 km distance between farms and centralized biogas plant go over 3.5 €/t making this operation on such distances practically not viable.

This paper aims to be a step forward in determining real and actual biogas potential from Croatian agricultural sector since family farms represents a big ratio of that potential and planning possible centralized biogas plants is one of the ways of utilizing that potential. One of the key issues in future research is also determining other substrate influences on the biogas plant profitability as well as finding the optimal mix of additional biomaterial used in fermentation. Based on current situation in Croatia and available data from neighboring countries (Stürmer et al. 2011), maize silage seems to be the most logical option both availability wise and economic profitability wise. With the implementation of other biomaterial used in the process, further analysis of transportation costs should also be made (Walla and Schneeberger 2008). In correspondence with the previously mentioned thesis, further analysis of available biomaterial needs to be done to have a clear picture of biogas potential of a certain region.

Conclusion

Centralized biogas plants are a possible solution for smaller family farms in Croatia. The profit itself is not the only and the main reason for farmers to participate in this venture. Farmers that participate in centralized biogas plants have the opportunity to manage their manure which will surely be important issue in the future for Croatia. Farmers would have the opportunity to process their manure and get fertilizer substrate from centralized biogas plants and earn more profits from selling manure on the side. In this case, nonmarket cost benefits of farm biogas plants would be an interesting topic for further research. Feed in tariff is an important issue when discussing biogas plant profitability and should be considered sincerely. In the case of higher feed in tariffs, net earnings for biogas plant owners would be significantly higher with bigger farms being more price sensitive regarding feed in tariff fluctuation. In the case of Feed in tariff 3 (1.3 HRK), this net earnings difference would go up to 12%. It is visible that the bigger family farms would have greater economic profit in selling their manure to centralized biogas plants. In the case of larger biogas plants studied through this paper (100,000 tonnes of manure per a year), the manure price at the biogas plant location would go up to 7 €/t, while the manure price on farm's location, for larger farms, would go up to almost 3 €/t. Based on the presented research, cases of Croatian farms that are more than 10 km away from the centralized biogas plant would not be eligible for participation in such a project. Farmers deciding to go in a joint ownership venture regarding centralized biogas production not only have a wider opportunity of earnings but also are taking more risks. More owners can complicate matters in the long run; so, this option should be considered with caution. Higher feed in tariffs would allow more centralized biogas plants and their wider regional distribution since they could retain the same profitability with smaller plant sizes, one of the future issues that needs to be investigated is the transportation operation. With transport modeling and routing, minimal farm sizes participating in the centralized biogas plant could be determined.

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