The good, the bad, and the nobody: Exploring diversity of perceptions of anaerobic digestion plants in Central and Eastern Europe

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ABSTRACT

Anaerobic digestion (AD) plants fed by agricultural biowastes are highly relevant renewable energy producers supporting the transition towards sustainable waste management. However, local support for the operation of individual AD plants seems to be highly diverse, case specific and generally insufficient. Following this challenge visible especially in Central and Eastern Europe, our research aims to detect and explain commonalities and discordances in the perception of AD plants in their host communities in Slovakia. Three types of rural communities in the western part of the country were selected for a set of comparative surveys as the illustrative case studies. We have selected: (i) the community where planning, building, and operation of AD plant did not cause any significant issues, (ii) the community, where significant controversies around operating AD plant occurred, and (iii) the community, where the AD plant project was stopped during the planning phase due to community resistance. We ascertained that in all three types of host communities, respondents claimed that AD plants worsen the local quality of life. In communities with the issues-free planning and operation of AD plants or where the project was stopped, the attitudes towards AD plants are rather constant. However, if community experienced issues with the AD plant operation, the overall support for biogas energy significantly worsened. Interestingly, a positive local experience with biogas supports further development of AD plants, however, only if these are located out of the host communities. Thus our findings enrich knowledge about the NIMBY effect with an Eastern European perspective.

Keywords: Anaerobic digestion plants, Perception, Community development, Agricultural change, Renewable energy, Slovakia

1. Introduction

The energy sector gradually moves away from the dominance and dependence on fossil fuels to more sustainable renewables together with the shift from the centralized to more evenly distributed and decentralized energy sources within individual countries and regions. The recent change of the mainstream narrative towards more environment-centred thinking when constructing our future energy strategies, is obvious around the globe **[1]**. Such a paradigm shift can be also undoubtedly traced in the post-socialist Central and Eastern Europe (CEE) that is long term geopolitically situated in a special and vulnerable position **[2]**. In CEE countries, advocating environmentally friendlier and sustainable energy production meets with the effort to advance the energy security that is linked to the unprecedented energy dependence on Russia **[3]**. It truly seems that this relation reached the new momentum in early 2022 when Russia invaded Ukraine.

Renewable energy sources (RES) are generally perceived as a much more environmentally favorable option for providing so urgently desired greater diversification of available energy sources **[4]**, and for making their spatial distribution more even, fair, and accessible. In this context, biogas generated from agricultural bio-waste has gained an important position in the energy transition **[5,6]** and the agricultural biogas energy production contributes to the accommodation of multifunctional approaches in agriculture and advancement with a real-life introduction of sustainability principles in agriculture and rural development **[7-10]**.

However, in addition to the economic, energetic, and environmental benefits, the operation of AD plant is also associated with negatively perceived impacts on their immediate neighbourhoods **[11,12]**. The perception of AD technologies is significantly worse than other RES **[13]**. We can trace many negative connotations associated with the biogas generation and AD plants operation such as the overall decreased well-being of population living nearby (e.g. by odour leakages, higher levels of transport, noise pollution, etc.) **[14]**, visual aesthetical landscape disturbance **[15]**, possible effects on attractiveness of the community for tourists **[16]**, and lowering the real estate prices in the neighbourhood of biogas facilities **[11]**. The change in the sowing areas structure in a favour of energy crops (i.e. maize) is common in CEE countries. Thus, a crop for a food production is reduced, which is certainly a strong argument against not that environmental and surely not sustainable biogas production **[17]**. Such development results in tensions within host communities that tend to escalate during the planning process **[18]**. However, the intensity of these tensions may evolve during the operational phase, which is highly dependent on the investor's behaviour towards the community **[16]**.

These tensions are frequently locally rooted in the specific sociocultural contexts **[19]** and are different among various geographical realms **[20]**. Only if accepted by local population the biogas production could develop its full potential **[21]**. The local acceptance (or lack thereof) is not solely about the agreement or ignorance but also about active behaviour of the locals towards the AD plant project that is manifested in the support or resistance **[14,22]**.

This is the reason why the main aim of the paper is to reveal and explain the dynamics behind different perceptions of AD plants in various localities with highly specific local planning decisions. We are focusing on the case study from Slovakia as an example showing considerable similarity in the development of energy production from AD plants to other post-socialist CEE countries **[6]**.

2. Conceptual background

2.1. Social acceptance of AD plants and perceptual changes

Social acceptance is widely understood as an active or passive agreement with certain policy or situation by the public **[23]**. It is often addressed in relation to RES installations, but there is no universal definition in the literature **[24]**. Nevertheless, scholars agree that gaining social acceptance belongs to the main challenges during the development of facilities for energy generation **[25]** including renewable energy projects **[26-28]**. This is the case for both (i) a general public-wide acceptance (or socio-political acceptance) and (ii) a local acceptance on the community level that is directly affected by a particular project **[24]**. This study focuses on the latter, for which the local socio-cultural implications of the location and operation of renewable energy projects are of extreme importance **[29]**. These are reflected in perceptions and attitudes towards specific RES installations, and thus express local or community acceptance **[29,30]**. The perceptions and attitudes of local people are not static, they tend to change depending on the phase of a particular project (announcement, planning, construction, operation) and the experience of the community, and thus the level of local social acceptance also develops **[24,29,30]**.

Insufficient social acceptance often stems from the fact that the benefits of the AD plants operation are frequently accumulated with investors at the expense of the local population **[31]**. But, there are several ways how to gain the support or at least the acceptance within the community **[32]**. It is crucial (i) to provide sufficient information, (ii) to be transparent in the relation to local institutions and people already in the initial phases of planning, (iii) and to ensure that a wide participation of local stakeholders in the project (like farmers, representatives of local and regional administration, local public, NGOs, local initiatives, citizen groups, etc.). Several other studies **[24,33-36]** confirm the importance of rigorous communication and sharing the information from the investor to the community and its representatives from the initial phases of the planning. The studies also emphasize the need to involve primarily the people living nearby AD plant, as participation in the decision-making process is the key for perception and the level of acceptance of biogas facility in the host community. It truly seems that the level of trust between the local community and AD plants operators significantly affects the level of local acceptance. It was found that if the AD plant owner is a member of the local community, the level of trust in the project is considerably higher than it is in the case of the out-of-community investors **[30,37]**.

While factors behind the acceptance and refusal during the planning phase of the biogas projects are intensively studied **[27,29,38]**, less attention is paid to what is going on in the communities after the renewable energy project gets to the operational phase **[14,37]**. Failing to provide sufficient information, providing of misinformation, concealing of the key aspects of the project and its expectable impacts on the community, may lead to the increase of the opposition against the realisation of the project and the public to avoid progress to the construction phase **[18,32]**. The lessons learnt show that even if such a controversial project was realised and started operation despite the critical public attitude, a level of public trust in the AD plant operator remained low and significantly impacted further development of the project and general perception of the whole biogas energy sector **[39]**.

The above findings show that perception of AD plants varies during the planning process and during the operation phase and is immensely dependent on the process and results of the planning phase. Thus, we can state our first hypothesis:

Hypothesis 1. Changing preferences during the planning and operational phases of AD plant depends on how the planning process was conducted and with what outcome.

2.2. Perception of different impacts of AD plants on communities

We are aware of the several key issues affecting the perception AD plant by the local public and stakeholders - e.g. prosperity in the community **[27,40]**, the level of environmental pollution **[41]**, the changes in wealth of agricultural business as AD plant operator **[42]**, and controversies arising from AD operation within the community **[38]**. Diversified positive and negative impacts of the AD operation were found. Operating AD plant is surely beneficial for farmers when diversifying and improving their farm economy, as well as it can be a way how to support social development by providing of the cheap heat supplies mainly in peripheral rural communities and particularly the poor. AD plant also has a clear potential to contribute to the improvement of the local environment when generating clean and sustainable energy based on processing agricultural waste **[42]**. It is without doubts that AD plants represent alternative and relatively stable source of income for farmers, provide new rural job opportunities, and contribute to the behavioural shift in the rural areas towards sustainability transition **[40,43-45]**. Beside discussing the pros, it is also necessary to deep dive into the cons and do not hide them so that potential effects on local wellbeing (like increased traffic and noise, odour leakages, etc.) can be mitigated **[27]**. Additionally, an overuse of purpose-grown maize as the feedstock for biogas energy generation has an unprecedented potential to replace and crowd out the food production from arable land nearby AD plant **[17]**. As has been proved by many studies, unfulfilled promises and expectations for the local use of the heat is also an issue **[20]** that burden successful operation of AD plant.

Similar issues were also detected in the western part of Europe **[19,23]**. Among the most frequently mentioned negatives were an odour, a noise, a purpose-grown maize to be energetically processed, and an increased traffic. On the other hand, the positives included the benefits for a local economy or more environmentally friendly way of an energy generation **[14]**. These findings allow us to formulate another hypothesis:

Hypothesis 2. The perception of the different types of impacts of AD plants on communities depends on how the planning process was conducted and with what outcome.

2.3. Preferences for the location of agricultural AD plant

While at the national level the studies frequently point out a strong public support for renewable energy, the picture becomes much diverse if we look at the local level **[27]**. It indeed appears to be proved that tensions and discrepancies exist among the support for renewable energy at the national (or even regional) level and locally site-based opinions based on the real-life experience with concrete AD projects. There has already been a wide set of literature developed around the NIMBY (Not-In-My-Backyard) concept **[41,46-50]**. Specifically, in the case of AD plants, the most frequently mentioned reasons for the local opposition are odour leakages, a noise pollution or the decrease of prices of real estates located nearby the plant.

To understand the NIMBY more thoroughly, we need to turn back to the theory, where especially the rational choice theory frames human behaviour as primarily motivated by own interests **[51]**. If we apply the theory to the problem of location of renewable energy projects, we clearly see that while this overall tendency is widely accepted and acknowledges by the general public, the issue occurs if a

given project is planned to be situated in the immediate neighbourhood of individuals. Then, the support for renewables, although supported by plentiful research-based and well-informed arguments, suddenly changes. On the contrary, a plenty of studies point out that such a simple explanation of the NIMBY concept is not complete as a rather one-sided perspective **[52]**. There are even some studies that deny the concept as insufficiently describing the issue and rather talk about an inverse NIMBY **[53]**.

Another highly relevant point seems to be that the population living in peripheral locations **[54-60]** or in post-industrial regions with worsen quality of the environment shows greater tendency to accept renewable energy projects in their communities **[61]**. Personal experience with AD plant could play here important role **[18]**. This is the reason why our last hypothesis was defined as:

Hypothesis 3. The preferences for the location of potential future AD plant projects depend on how the planning process was conducted and with what outcome.

3. Data and methods

3.1. Study area

Slovakia (population of 5.46 million on the area of 49,035 km^2) belongs to the CEE countries with the well-developed national level support for generation of biogas energy and its further utilisation **[62]**. This factor has driven our decision to use Slovakia as a case study representing the post-socialist realm of the CEE countries. Similarly advanced biogas sectors can be also found in neighbouring Poland and the Czech Republic **[62]**. The first AD plant in Slovakia started operation in 2005 however the biogas sector recorded a rapid development as late as in the decade following the approval of the Act on the Promotion of Renewable Energy Sources (Act 309/2009) and the National Action Plan for RES (National Action Plan for RES, 2010) that were adopted in 2009 and 2010 respectively. The number of operating farm-fed AD plants stabilized quickly at around 70 with the total installed capacity of 65 MW **[16]**. In 2021, the overall number of operating AD plants in Slovakia was more than 110 (with 115 MW of the installed capacity) **[63]**.

The vast availability of the feedstock and the increased utilisation of biogas undoubtedly belong to the ways how to gradually solve precarious geopolitical energy situation of Slovakia at the eastern periphery of the European Union. First, Slovak domestic reserves of energy sources are extremely limited. Out of renewable energy sources, due to Slovak geographical conditions, hydropower is among the major energy sources (14% of the gross electricity production **[64]**). Other minor domestic energy source is lignite that is burned in coal power plants; however, to cover its demand it must be partially imported. Consequently to the national decarbonisation policy the coal mining concentrated in the western part of Slovakia will be closed by the end of 2023. The most important energy sources for the electricity generation are two nuclear power plants (circa 55% of the gross electricity production) and the natural gas for the heat production **[64]**. The natural gas alltogether with nuclear fuel is imported from Russia. Such a dependency makes the country vulnerable in the terms of energy markets imbalances as well as geopolitics **[65]**.

The utilisation of the vastly underused renewable energy sources is the most promising way how to transform the Slovak energy system towards sustainability and at the same time to release it from the dependency on energy resources from Russia. It is absolutely essential for the country's future to increase its energy self-sufficiency and security with strong environmental aspects taken seriously into the account **[66]**. AD plants if reasonably managed and fed by suitable feedstock could play a highly

relevant role in achieving this goal **[62]**. These factors are challenging not only for Slovakia but also for other post-socialist CEE countries that are also coal dependent and keep importing a large share of natural gas from Russia **[2,67]**.

3.2. Selection of the sites

Reflecting the aim of our study and the conceptual framing of our research, we selected three AD plant host communities in Slovakia for an in-depth study. Our three case study communities had to comply with the following principles. We selected:

- a community where the operation of AD plant is not accompanied by major problems, labelled for further use also as "accepted",
- a community where the operation of AD plant is associated with severe problems, labelled for further use also as "controversial", and,
- a community where planned AD plant was not built, labelled for further use also as "not realised".

All three case studies were selected from the territory in northwestern Slovakia (**Fig. 1**). The selected communities are situated in the countryside and characterized by the comparable population sizes (800-1400 inhabitants), similar geographical locations as well as sociocultural characteristics. We selected the projects where the period of the planning phase and the planned construction was approximately the same (2010—2013), where the anaerobic digestion is based on a similar feedstock, and where the locations of the AD plant relative to the residential areas are similar. We considered the projects with the similar installed capacity (1 MW) announced in the planning phase. The investors and owners of all surveyed AD plants are private companies. With such a methodological approach, we attempted to reduce the impact of the site-specific spatial and socio-cultural attributes on the findings. All surveyed communities are located in the foothill areas of the Považské podolie Valley featured even with similar agricultural conditions with an above-average proportion of oilseeds and sugar beet **[68]**. All three AD plants are situated in the peripheral parts of the surveyed communities that are densely concentrated to the narrow bottoms of valleys resulting into the high local population densities. The closest residential homes are located just around 100-200 m from existing or planned AD plant in all three cases. Two operating AD plants are located in the premises of farms following the former large-scale socialist agricultural cooperatives. This kind of farms are still typical for Slovak agriculture.

As outlined above, we selected three AD plant communities for our in-depth research that are thoroughly described below. The final selection of three specific case studies was based on the results of a previous series of controlled interviews with representatives of municipalities and AD plants operators in seven localities in the region.

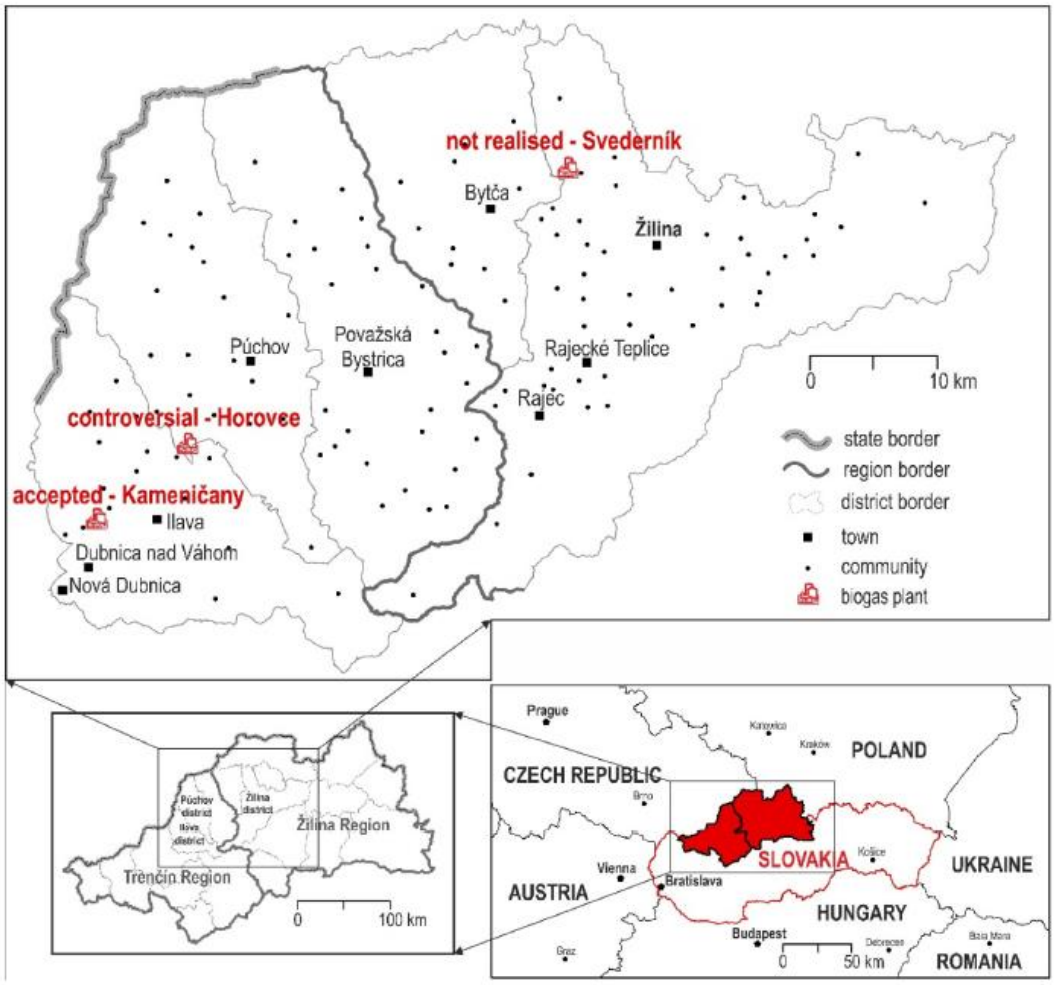

Fig. 1. Geographical location of the case study communities.

3.2.1. Accepted

Kameničany was chosen as an example of the community where neither location nor operation of AD plant brought any significant controversies. AD plant was built in 2012 with the installed electric capacity of 1 MWe as a joint venture of nearby farm focused on cattle breeding and a company focused on generation of agricultural biogas. AD plant is located in the former area of a pig farm with a characteristic odour. Only a few residents living in immediate vicinity of AD plant disagreed with the project in the planning phase. Based on the initiative of the mayor, the investor organised a site visit for the residents to a similar AD plant operating in Austria. All the feedstock (circa 30,000 tons; **Table 1**) is produced on own farm which is located in administrative territory of the neighbouring community of Bolesov. AD plant was commissioned before the national regulations introduced the obligation to utilize at least 50% of the heat generated as a by-product of biogas production. However, the operator of AD plant was actively seeking such options. In 2014, large-scale greenhouses (on the area of 3 ha) used for a tomato production were built. As much as 70% of their heating is covered by AD plant. AD plant is situated in the northern part of the Kamenicany community (population 560 in 2020), about 200 m from nearest residential homes. Similarly distant from AD plant is a newly built (after AD plant started the operation) residential part of the neighbouring Slávnica community (population 800 in 2020). Both municipalities form a compact unit of built-up areas, which is divided only by the

administrative border **(Fig. 2)**. Therefore, we decided to examine both municipalities as a whole. In the terms of an installed capacity, this AD plant represents a typical AD plant in Slovakia. It was included in our study as a case of "accepted" AD plant, when both the mayor and the operator as well as the local community agreed the mutual communication during both planning and operation phase has been fair. The investor and the representatives of the municipality jointly participated in the information campaign organized for the residents. The municipality currently smoothly cooperates with the farm and AD plant. AD plant is fed by locally produced feedstock including agricultural waste, which minimizes the level of local traffic. The investor often funds cultural and social events in the community. Greenhouses utilize the heat generated in AD plant and offer local job opportunities and, in a period of increased interest in domestic agricultural production, also help in building a positive image of the village.

Table 1 Basic information about the three AD plant case studies.

Label	Community	Commissioning	Electric installed capacity (MWe)	Feedstock	Re-use of heat
Accepted	Kamenicany	2012	0.999	Maize, manure, hay	Heating of a large-scale glasshouse for tomato production
Controversial	Horovce	2010–2013	Total: 2.996 Unit 1: 0.999 Unit 2: 0.999 Unit 3: 0.499 Unit 4: 0.499	Maize, rye, haylage, chicken and cattle manure, beet pulps, food waste, urban greenery	Heating of on-site buildings, halls, offices. The plan for connecting residential homes was not realised.
Not realised	Svedernik	2013 (planned)	0.900	Maize, manure	Heating of on-site halls and offices.

Source: Own research.

3.2.2. Controversial

Horovce (population 850 in 2020) is a case of the community where the operation of AD plant is connected to severe controversies. The plant is situated within the premises of a former large-scale post-socialist agricultural cooperative in the northern margins of the community **(Fig. 3**), only about 150 m from the nearest residential blocks. At the beginning of the planning phase, an AD plant project with an installed capacity of 1 MWe was announced to the community. Even then, the project has been accompanied by the disapproval by the local population, mainly the residents of the nearest blocks. Even the local petitions did not persuade the investor and the municipality representatives to change or stop the project, and the municipality allowed the construction. The original plan promised the supply of cheap heating for the nearest blocks as a benefit for the residents. However, this promise has never been fulfilled. In addition, despite the other petitions and opposition from the local population, the local authority allowed further expansion of the plant, which created a complex of four units located next to each other (and next to residential area) with an installed capacity of almost 3 MWe **(Table 1)**. First biogas unit launched the operation in 2010. Due to the ignoring of complaints and demands of the locals, the AD plant became a major issue resulting in elected mayors and deputies in 2014 whose campaign was based on the objection on the AD plant. The feedstock in not on-farm produced and is purchased from the external suppliers (mainly farms in the region, partly from other parts of Slovakia and even abroad). The electricity generated in AD plants is supplied to the grid, heat is used solely within the farm to cover own energy needs (heating of the offices and halls). The reasons for labelling AD plant as "controversial" involve insufficient and incomplete information provided by the investor in the planning phase, failure to address the objections and complains of the residents, unfulfilled commitments of the investor, excessive size and inappropriate micro location of AD plant.

The potential of the location simply cannot cover the needs for the feedstock, which increases the need for imports and also increases local traffic load. Similarly, local agriculture does not have the capacity to utilize all the digestate produced. The use of the heat produced in AD plant is insufficient. Relations with the representatives of the community are frozen, and the investor of the AD plant does not provide any support in the form of sponsorship for the community.

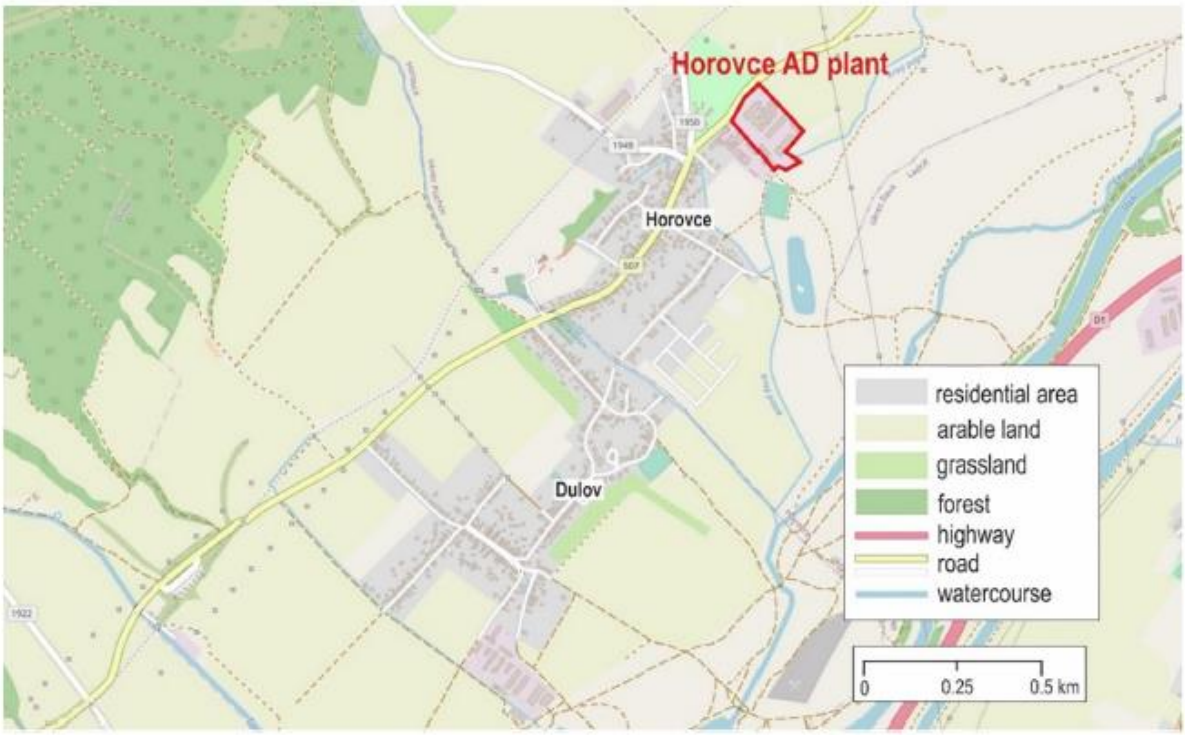

Fig. 3. Location of Horovce AD plant.

3.2.3. Not realised

AD plant in the community of Svederník (population 1200) was planned but the investment was stopped due to local opposition. The plan originates in 2013 when the local company operating photovoltaic power plant in the community introduced the biogas energy project (with planned installed capacity of 0.9 MWe). It was to be located only about 200 m from the residential area (Fig. 4). The implementation of the project was soon stopped due to opposition from the community and its representatives. Additional factor that contributed to the refusal of the project was unclear source of the feedstock for generation of biogas (90% was planned to be covered by maize, 10% by manure). The presented project did not include any benefits for the community. The project involved the re-use of heat for on-site halls and offices and two new job opportunities. We have to stress that this is a relatively rare case in the context of Slovakia as there are not many AD plant projects that would be suspended due to disagreement of the local residents.

More information about the individual AD plants is provided in **Table 1**.

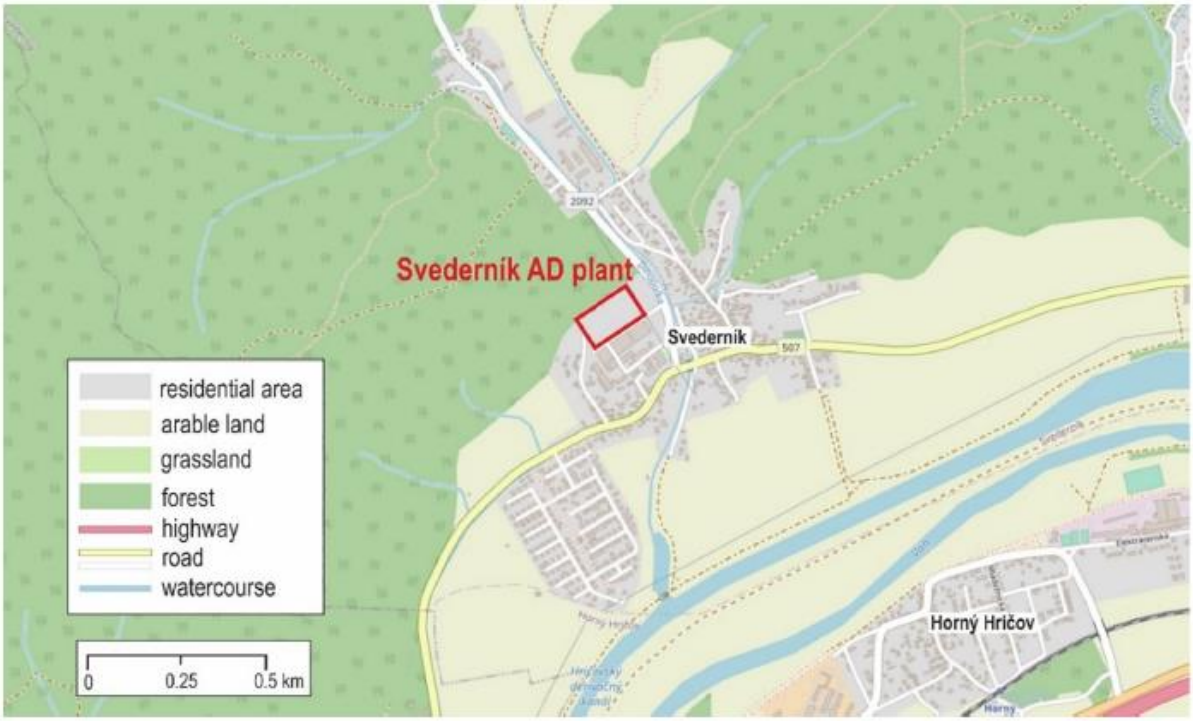

Fig. 4. Location of not realised AD plant in Svederník.

3.3. Data collection

Based on the literature review regarding the logic behind the aim of our research, three hypotheses were defined and quantitative research methods including the collection of primary data were selected as appropriate research techniques. We principally aimed to build the database enabling to apply a set of statistical analyses to advance with our understanding of the research problem **[69]**. As either means or counts we intended to accommodate to test our hypotheses, similar number of respondents from each locality was surveyed **[70]**. This approach was found to be valid as the amount of the population residing in the neighbourhoods of each AD plant was quite similar in all three locations and varied between 1000 and 1200 inhabitants (to be clear, the overall number of affected population is higher as in two cases settled parts of communities are integrally connected to the neighbouring communities). Our aim was to gather completed questionnaire from circa 10% random sample of each community's population; thus 150 respondents were targeted to be approached in each of the three locations. Our respondents were interviewed on the streets of the villages during the week days. Completion of one the questionnaire took circa 15-20 min. The randomness of the sample was ensured by the selection of every second person passing by. If the group of people was passing by, only one person from the group was asked to participate. Only adult (over 18 years) permanent residents of the three communities were interviewed. Altogether 450 respondents were asked to participate in the survey that was carried out during the 14 days of the fieldwork in April 2018. This survey was undertaken by the first three authors together with trained university students. The refusal rate was calculated for 31% and 309 fully answered questionnaires were available for our analyses.

3.4. Questionnaire

As quantitative data were of our interest, only 5-point scales or definite list of items were used. The questionnaire consists of four main parts and was designed so that its results would enable thorough testing of our three hypotheses.

The first part of the questionnaire was prepared to explore general attitudes to the specific AD plant before its construction (in the planning phase) and after its construction (in the operational phase). Two questions were asked: (Q1) "In your community, biogas plant is or was planned to be operated. Could you please state if you agreed with this project?" and (Q2) "If we turn back in time before biogas plant was built, would you agree with its construction based of your current experience?" The answers to both questions were measured on a 5-point scale (where 1 = definitely yes, 2 = rather yes, 3 = I do not know, 4 = rather no, 5 = definitely no). The difference between the responses to these two questions was used as an indicator of the shift in the attitudes resulting from an experience with AD plant in the community.

Following part of the questionnaire was aimed to understand perception of AD plant operating in a given community in detail (Q3) using semantic differential. This part consisted of seven bipolar pairs of possible effects of AD plant on the community where respondent lives. The items asked were prepared on the basis of previous studies **[14,19]**, and covered all the main topics regarding the impacts of AD plants on the life in hosting communities. Following bipolar pairs of questions were asked:

- (Q3a) AD plant endangers the environment. AD plant contributes to the protection of the environment.
- (Q3b) AD plant has a negative impact on agriculture. AD plant has a positive impact on agriculture.
- (Q3c) AD plant has a negative impact on the local economy. AD plant has a positive impact on the local economy.
- (Q3d) AD plant discourages the tourists. AD plant attracts the tourists.
- (Q3e) AD plant negatively affects the image of the community. AD plant positively affects the image of the community.
- (Q3f) AD plant worsen quality of life in the community. AD plant improves the quality of life in the community.
- (Q3g) AD plant contributes to the conflicts within the community. AD plant soften the conflicts within the community.

The perception of each item was measured separately on a 5-point scale (from 5 = I definitely prefer the right variant, to 1 = I definitely prefer the left variant).

The future vision for AD plants in host communities was supposed to be indicated by responses to the question in the third part of the questionnaire. To respond the question (Q4) "What is your personal attitude towards further development of AD plants?", a respondent could choose from the following answers: i) "AD plants shouldn't be built at any locality," ii) "AD plants should be built but not in the proximity of my community", and iii) "I don't mind if another AD plants are built in the proximity of my community."

The fourth part of the questionnaire encompassed the questions regarding the demographic and socio-economic status of the respondents. The sample for statistical analyses is summarized in **Table 2**.

The original version of the questionnaire was tested on the sample of 20 volunteers in March 2018. Consequently, minor changes regarding especially wording of items in Q3 were carried out based on results of this pre-test.

3.5. Data analyses

To test our first hypothesis, the differences between the attitude towards AD plant in the planning phase (before construction) and in the operational phase were tested by the means of the One-way Analysis of Variance (ANOVA). The results were post-hoc tested by the Tukey post-hoc test for unequal n, as different numbers of responses were obtained from locations under study.

Our second hypothesis required to be tested in several steps. Firstly, the overall difference among our three study sites was tested by the Multivariate ANOVA (MANOVA) as we have measured multiple response variables and we want to test them simultaneously. Then, to find out which of the dependent variables differ across the communities the One-way ANOVA with the Tukey post-hoc test for unequal n was employed.

Table 2 Characteristics of the respondents in three AD plant communities.

	"accepted"	"controversial"	"not-realised"
Number of respondents	116	107	86
Gender (share of females)	50.0%	55.1%	53.5%
Age (mean of years)	46.4%	48.6%	46.7%
Education			
Basic	04.3%	07.5%	02.3%
Secondary without graduation	28.4%	29.9%	25.6%
Secondary with graduation	53.4%	50.5%	53.5%
University	13.8%	12.1%	18.6%
Economic status			
Self-employed	07.8%	10.3%	12.8%
Employee	41.4%	43.0%	38.4%
On parental leave	06.0%	04.7%	04.6%
Retired	31.9%	31.8%	29.1%
University student	08.6%	07.5%	09.3%
Unemployed	04.3%	02.8%	05.8%
Natives (share of people born in the community)	58.6%	62.6%	59.3%

As the counts were obtained from the question related to our third hypothesis, the Chi-square test was used. The counts for the answer were tested in a 3 x 3 matrix as three locations were investigated and three levels of individual responses requested. The results were visualized utilizing the Pearson residuals of observed and expected values in the dot plot, where the size of the circle is proportional to the amount of the row and column contribution to a chi-square. Positive residuals (observed values were greater than expected values) are shown in the shades of blue, on the other hand, negative residuals (expected values were greater than values observed) are depicted in the shades of red **[71]**.

The One-way ANOVA with the Tukey post-hoc tests were prepared in the Tibco Statistica software **[72]**, a chi-square test with dot plot were prepared in R using corrplot package **[73]**.

4. Results

The shift in attitudes towards AD plant differs significantly among the three case studies (One-way ANOVA: F(2, 306) = 11.816, *p* = 0.00001, **Fig. 5**). Based on the Tukey post-hoc test for unequal number of n, we can state that the pattern of the shift is the same in the cases of the "accepted" and the "not realised" AD plants. In both cases the attitudes towards AD plants when conducting survey were very similar with these in the planning phase (average differences are oscillating around zero). On the contrary, in the "controversial" AD plant case study, the attitudes towards AD plants in the planning phase and in the operational phase showed a significant shift. Apparently a real-life experience with the operation of AD plant led to a fundamental deterioration in attitudes.

Worsened acceptance of AD plant in the "controversial" case is also reflected in the perception of the impacts on the community as whole MANOVA is highly significant (Wilks lambda = 0.64194, F(14, 600) = 10.633, p < < 0.001). Six out of our seven measured dependent variables differ among the three study sites **(Table 3, Fig. 6)**.

Improved perception was recorded in the "accepted" case study community, while the best results were ascertained in the "not realised" case **(Fig. 6)**. The post-hoc test revealed considerable differences among all the three case studies when asking if AD plant contributes to the protection of the environment or threats it, if the impact of AD plant on the local economy is positive or negative, and if AD plant contributes to the image of the community positively or negatively.

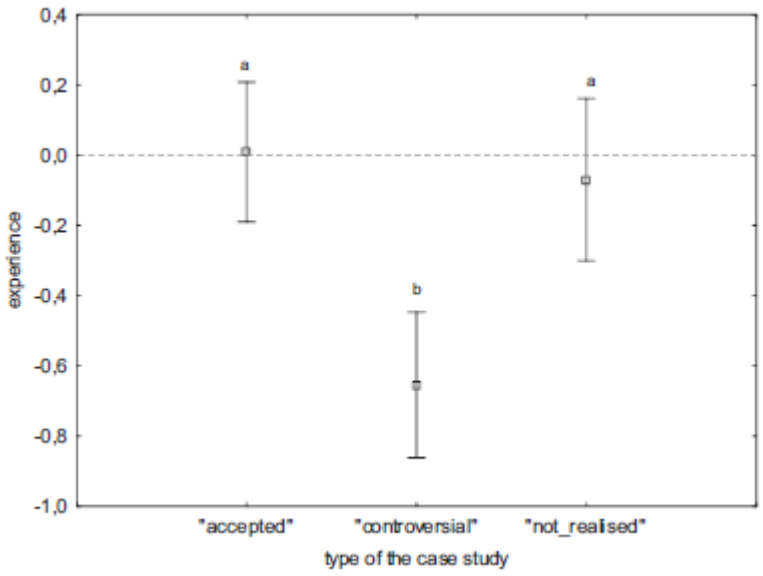

Fig. 5. The mean differences and its 95% confidence intervals between acceptance of AD plant in the planning and operation phases. Means with the same letter do not differ significantly (Tukey post-hoc test for unequal n, $p < 0.05$).

Table 3 Results of the One-way ANOVA, hypothesis 2. Means with the same letter do not differ significantly (Tukey post-hoc test for unequal n, $p < 0.05$).

	F	p	Means					
			"accepted"		"controversial"		"not-realised"	
Environment	22.09	<.001	2.46	a	1.68	b	2.94	c
Agriculture	26.71	<.001	2.95	a	1.95	b	3.27	a
Economy	28.52	<.001	2.30	a	1.81	b	3.05	c
Tourism	17.59	<.001	2.10	a	1.45	b	2.35	a
Image	16.48	<.001	2.30	a	1.72	b	2.84	c
Quality of life	1.09	n.s.	2.14	a	1.98	a	2.14	a
Conflicts	16.38	<.001	2.81	a	1.92	b	2.22	b

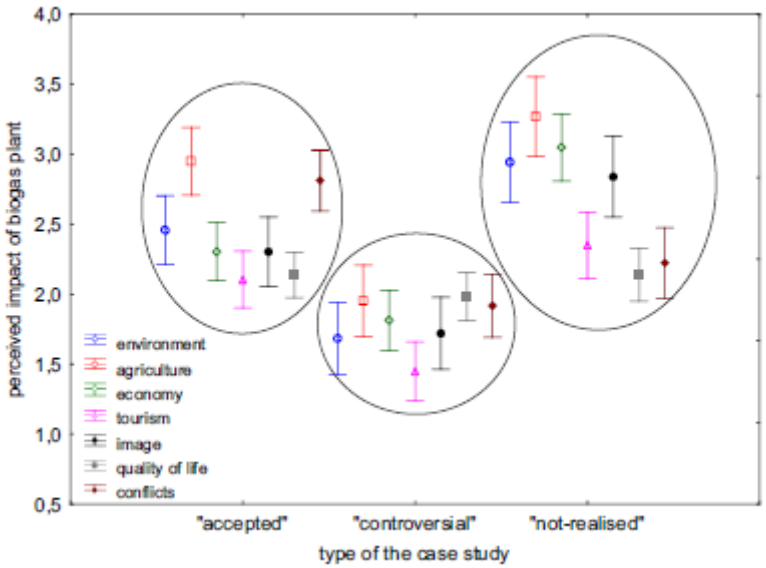

Fig. 6. Mean values and its 95% confidence intervals for seven measured perceptions of different impacts of three AD plants.

In the questions if AD plant has a positive or negative impact on agriculture, and if AD plant attracts or discourages tourists, the replies from the "accepted" and the "not realised" case were similar, while the replies from the "controversial" case study were much more pronounced negative.

However, the pattern of perception was different in other two areas of the impacts of AD plant. The impact of AD plant on quality of life is perceived negatively in all three types of communities without statistically significant differentiation. On the other hand, AD plant in the "accepted" case is perceived as a factor softening conflicts in the community, but as a factor contributing to the conflicts in the "controversial" and "not-realised" cases **(Fig. 6)**.

Attitudes as to whether and where new AD plant projects should be implemented vary considerably among the three communities surveyed (Chi-square: 64.6723, d.f. = 4, p ≪.001; **Fig. 7**). The chi-square value is the most importantly fed by the opinions of the "controversial" case study. Locals seem to believe that AD plants should not be further developed anywhere. Another statement that significantly contributes to the very high value of a chi-square test, is a strong voice from the "accepted" that AD

plant certainly should be further developed but not within their community (the NIMBY attitude). On the other hand, in the “not-realised” case, an above-average share of the population expressed their opinion that future AD plant could be located anywhere (including their community).

5. Discussion

All three defined hypotheses were confirmed by statistical analyses of primary data obtained in our survey. Undoubtedly, interesting findings highly important for both the AD plants perception theory and practise were detected. Especially, the bad experience with the operation of the controversial case of AD plant remarkably influences the overall perception of the biogas generation. This finding has an immense impact on different aspects of perception of the influence of AD plant on the hosting community. Similarly, the impact can be clearly seen on the support for the development of AD plants in surroundings of the community and beyond.

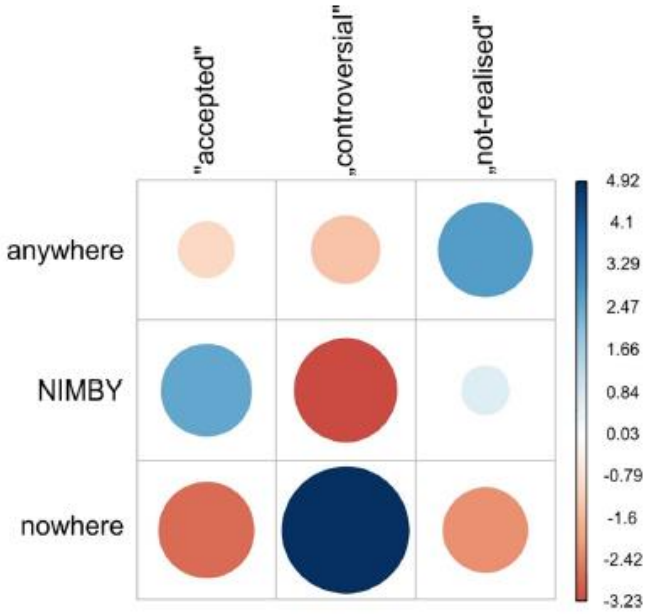

Fig. 7. Cross-tabulation of the preferences for future development of AD plants across the three case studies.

5.1. Experience and changes in perception of AD plants

We know from previous studies that numerous factors affecting the level of perception of AD plants in their communities exist. The exact location of AD plant within the community is among the most influential factors. Schumacher and Schultmann **[19]** claim that only 18.5% of the population living within the 1 km distance from operating AD plant is persuaded that such a distance is sufficient. Both communities with operating AD plants in our case studies (“accepted”, “controversial”) confirm this finding. Surveyed AD plants are situated in immediate proximity of residential areas, which indeed contributes to rather negative attitudes towards local AD plant. The reasons behind these attitudes are particularly odour leakages, a noise pollution and an increased traffic. Nevertheless, in many respects we observed fundamentally different perceptions of operated AD plants.

Another decisive factor affecting the way how AD plant is perceived in the hosting communities is the behaviour of the owners or operators of the plant during the planning (like sharing transparent and accurate information with community or endeavour to actively engage community to the planning and decision-making, etc.) and the operational (like benefits sharing, problems solving, etc.) phases **[37]**. In the case of AD plant where the public was actively involved in the planning phase, where the information shared by the investors was transparent and truthful, where sharing misleading information or concealing the information was avoided, and where benefits of the AD plant operation were shared with the community, the public support is significantly higher. What can be also stressed that also a personal experience with the operation of AD plant in a form of the direct visit in the facility can be relevant tool to increase the acceptance of biogas energy **[16]**. The authors claim that the respondents who personally visited AD plant, express more positive attitudes towards AD plant than those who had no opportunity to visit or did not take such an opportunity. It is also obvious from the results of the previous studies that in cases where the communication between the investor and the community was limited (or even none) or the promised plans to share benefits from the AD plant operation (local supplies of heat predominantly) were not fulfilled, a negative perception of these facilities prevails. This is confirmed by the research carried out in the AD plant case study from eastern Slovakia, where heat supplies were promised to be used for heating of municipal buildings, family houses or greenhouses in the community during the planning phase **[62]**. However, none of these intended projects was implemented, which significantly worsened the perception of a local AD plant.

Such a variety of driving forces behind the level of acceptance of AD plants is clearly visible in the three communities of our interest. This is particularly evident in the case of the "controversial" case study. The original plans involved provision of heat to nearby residential buildings but this plan failed to execute. Many respondents used this argument to justify their negative attitude towards local AD plant. The most negative attitudes towards AD plants were related to deterioration of quality of life in the community and minimal benefits shared with the community. In principle, the respondents claimed that the operation of AD plant is beneficial for the investor only and not so much for the community that is undoubtedly affected **[20]**. Similar findings were revealed in the study by Kortsch et al. **[14]**.

Another significant driving force affecting the perception of AD plant within the host community is a factor of certain match between the location of AD plant, its size and the local socio-cultural and environmental potential available on-site **[74]**. In the "controversial" case, none of the above was reflected, especially in the phase of expansion of the originally announced one-unit AD plant to four-units complex, despite the protests of the community. The amount of locally produced feedstock is simply not able to cover the needs of such a large AD plant facility. Consequently, increased pressure to ensure fluent supplies of the feedstock from elsewhere leads to the increased traffic and worsen local wellbeing. Although local inhabitants do not perceive the size of the installed capacity of the AD plant, they are sensitive to the burden on transport, the environment and the quality of life that the expansion of the AD plant brought. Although benefits for the community were promised by the investor in the planning phase of the "controversial" case (as the provision of the cheap heat, sponsoring of local events, cleaning roads, or sharing of some of AD plant equipment for the needs of the municipality, etc.) **[20]**, these plans have never been realised. In other words, there are no compensation measures to mitigate the negative impacts of AD plant on the community.

In the "accepted" case, the change between perception in the planning phase and after years of operation is minimal. In this case, the investor communicated with the host community since the planning phase, the original plan to use the heat from AD plant in a large-scale greenhouse was completed and offered new jobs for the locals. As this AD plant is smaller (0.999 MW) when compared

to the “controversial” case, the scale more suitably corresponds with the natural potential and availability of the feedstock in the area. The operator of the “accepted” case uses the feedstock from its own agricultural production resulting in not so significant impact on the increased traffic. As the main traffic route leading to the AD plant passes directly through the residential area in this case, we assume that a more significant increase in traffic due to the operation of the plant would be perceived very sensitively by the community.

In the “not realised” case, where a direct experience of the community with operating AD plant is lacking, we ascertained rather positive perception of AD plants. This result is quite surprising as the AD project was not materialized in the community clearly due to the local opposition against the project. To show more from the project background, the investor of the intended AD project was known in the community as he has already operated a solar power plant in the community. It seems that negative attitudes towards the implementation of AD plant are connected to the initial expectations that if the investor or operator is known in the community, the approval will be smooth and the acceptance rather high **[37]**. However, the results of our survey provide an explanation. The local community indeed perceived the potential benefits for the community as insufficient. Moreover, the intended structure and scale of the supply of the feedstock was also criticized, as the investor did not plan to use the feedstock potential of other farms in the region. Such a challenge is at odds with trends in Slovakia, where due to the existence of the remnants of large socialist agricultural cooperatives, most of the operated AD plants are situated within their premises which suitably enable at least some extent use of their own production (or waste) as the feedstock. On the other hand, in nearby Poland, AD plant operators usually operate as separate entities that import feedstock from elsewhere **[62]**. This approach is very similar to what has been experienced in the planned, but “not-realised” case of AD plant.

5.2. Impact of AD plant on the community and NIMBY effect

If we focus now more on the evaluation of the impact of AD plants on the host communities, certain patterns can be surely followed. In all surveyed communities, the impact of AD plants on quality of life in the host community was perceived as negative. This seems to be affected by the location of AD plants at too short distances from the residential areas. Similarities were also detected in the opinion that AD plant causes the conflicts within the community. In our two cases with operating AD plants (the “accepted” and the “controversial” case) we found the conflicts between the operators and the community. Additionally, an open conflict in the “controversial” case was found between the AD plant operator and the political representation of the community. Our results are in aligned with the findings of the study by Chodkowska-Miszczuk et al. **[20]** where the most critically perceived were the issues around the quality of life and benefits for the community. In other spheres (like the impact of AD plant on agriculture, local economy, and image of the community), we clearly see diversity in the public opinion in the individual surveyed communities. By far the worst perceptions of these attributes were detected in the “controversial” case, contrarily, more positive approach was found in the “accepted” case and the most positive perceptions were found in the “not-realised” case. In general, such a diversified development of perception contradicts other findings stressing **[75,76]** that the social acceptance of renewable energy projects tend to rise after the facility is in the operational phase.

The opinion of the public concerning the development of new AD plants noticeably reflects the local experience with the planning and operation of these plants. While the vast majority of the population of the “controversial” case (the community with a negative experience), declares that AD plants should not be built anywhere, in the case of AD plant in the “accepted” case are more pro-biogas plants

oriented but only if these are built in other communities (the NIMBY effect is obvious here). The most positive evaluation of the AD plant issues can be found in the "not realised" case, where the direct experience with operational AD plant is lacking.

There is no doubt that the NIMBY effect substantially impacts perception of further development of the biogas sector. It seems that among the ways how to, at least partially, overcome this problem, undoubtedly it is the systematic inclusion of benefits for the individual AD plant host communities **[50,52]**. In other words, the local population requires sharing the benefits from AD plant operation that do not necessarily have to be of the financial nature **[77]**. Incorporation of AD plants into wider local and regional strategies to systematically deal with energy poverty and social uplift of rural peripheries seems to be the right further step to be conducted **[78,79]**.

6. Conclusions

Our findings confirmed that significant differences are detectable among experiences and attitudes in the communities where AD plants are operated. Our results also contribute to the recognition that both acceptance and rejection of individual AD plants in the host communities is gradually formed from the early stages of the planning. Therefore, the AD plant projects are enormously sensitive and vulnerable for any kind of misleading and not accurate information shared with the locals in the planning phase. Conflictual project history surely does not support the success of the project. Contrarily, it seems that the attitudes towards AD plant in the operational phase correspond mainly to whether the community perceives the AD plant operation benefits more strongly or rather feels negative consequences. Having in mind the case-specific nature of our research, our findings highlight that the following principles can contribute to a positive perception of AD plant in the community or even to partially mitigate negative consequences:

i) the location of AD plant within community needs to be carefully considered respecting local socio-cultural and geographic conditions and natural potential of the area,
ii) the host community is encouraged to participate in every phase of the planning and operation of AD plant; participation in early stages of the planning phase should not be underestimated,
iii) the information provided by the AD plant investor to the local public is truthful, accurate and transparent,
iv) the investor's commitments made towards the community during the planning phase are fulfilled so the mutual trust is nurtured,
v) AD plant is embedded in life of the community and pro-actively participates in the community building,
vi) benefits from the operation of AD plant are shared within the community, especially with those affected the most, and
vii) the operation of AD plant is subject to change in time due to both external and internal factors and thus, the relations with the community require renegotiations if needed.

Based on our set of surveys it can be confirmed that the perception of AD plants among the local public is diverse. Both positive and negative personal experience with the operation of AD plant has a tremendous impact on the attitude of the community not exclusively to the local AD plant, but more widely, to the production of biogas energy in general. There is no doubt that a personal experience with individual types of AD plants studied in this paper thoroughly affects the public opinion and thus integrally contributes to the formation and development of a society-wide attitude towards not just biogas energy but also overall acceptance of renewable energy generation.

We are well aware that the presented research concentrated in one small-sized European country and in three case studies has certain limits, but we are convinced that the above conclusions are relevant and contribute to filling the gap in the research of the society's attitudes towards renewable energy projects. This study also provides a piece knowledge and methodological basis for further research, where the attitudes of communities in other cultural and economic conditions, including international comparisons could be examined. Such a crosscultural approach will enable us to develop a typology of the good practice in the AD plants operation, and so contribute to more sustainable generation of biogas energy generation with reduced negative consequences. Additionally, we believe our findings enrich current knowledge about the NIMBY effect with an Eastern European perspective.

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