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Where AD plants wildly grow: The spatio-temporal diffusion of agricultural biogas production in the Czech Republic

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Abstract

There is fundamental agreement about the environmental benefits of renewable energy technologies, but unintended consequences arising from their deployment are frequent sources of conflicts. The Czech Republic has committed itself to supply 13.5% of its electricity consumption from renewable sources by 2020. High state incentives for renewable energies have been provided to achieve this target, however critical questions can be asked about the appropriateness of the design of the supporting frameworks which caused a boom in photo-voltaic (PV) installations on agricultural land, as well as a boom in the installation of agricultural anaerobic digestion (AD) plants fueled by dedicated energy crops. This paper analyses the diffusion of agricultural AD plants in the Czech Republic, focusing especially on locational characteristics in relation to the quality of agricultural land, agricultural and population census data. Statistical analysis of those spatial datasets show that agricultural AD plants are mostly located in less favourable agricultural areas, in regions having recently experienced a reduction in cattle breeding, and in regions with significant increases of sowing areas of green maize. These findings suggests shortcomings in the supporting policy for AD plants in the Czech Republic, resulting in unintended environmental consequences, and missed opportunities to enhance energy self-sufficiency and resilience in the countryside.

Keywords
Agricultural anaerobic digestion plants, Czech Republic, Spatial determinants, Spatial analysis

1. Introduction

There is widespread scientific consensus on the need to decarbonise our energy supply, but on the political scene opinions about support for renewable energy development are much more diverse and colourful, ranging from utter adoration to complete condemnation (e.g., Meyer [1]; Jacobsson and

Lauber [2]; Lipp [3]; Fouquet and Johansson [4]). As the renewable energy sector has developed over the last decade, it has exposed or raised different political issues in different countries (Reiche and Bechberger [5]; Jacobsson et al. [6]). Under-represented in the international academic literature, the fate of renewable energy in Central European countries provides an interesting test case of economic versus environmental motives (Ryvolová and Zemplinerová [7]), which can be revealed in a closer analysis of state support for renewable energy, be it financial incentives for construction or generation (Ringel [8]; Butler and Neuhoff [9]; del Rio Gonzáles [10]; Coutur and Gagnon [11]). The commitment of the European Union to cover 20% of its energy consumption from such sources by 2020 (Directive of the European Parliament and Council no. 2009/28/EC from April 23, 2009 [12]) allows considerable flexibility to individual member states. Implementation is essentially left to individual governments who can chose different forms and levels of support to achieve their contribution to the 2020 EU target. While the Czech Republic has undertaken to cover 13% of its gross final energy consumption from renewable sources by 2020, in Poland it is 15%, in Slovakia 14%, in Germany 18%, and in the case of Austria 34%. However, approaches to meet these commitments are also vastly different (Haas et al. [13], Kitzing et al. [14]). In the Czech Republic, financial support has resulted in a huge boom in photo-voltaic (PV) (2009–2010) and anaerobic digestion (AD) (2011–2013) installations. This support has helped the country to meet its obligation to the European Union but has also led to many unintended environmental consequences (Dincer [15]). As a result of misleading settings of the supporting frameworks for the subsidy of renewable energy in the Czech Republic, more than 4000 ha of agricultural land have been covered by PV installations (Klusáček et al. [16]), and more than 300 agricultural AD plants have been constructed. The latter are primarily fuelled by purpose-grown green maize, utilising only a limited amount of agricultural waste (Martinát et al. [17]). The biogas is used to generate electricity for the grid, whilst the co-produced heat is exploited only to a very limited extent (Martinát et al. [18]), a lost opportunity to serve the heating requirements of adjacent rural communities (Van der Horst [19]). Moreover, in light of a series of scandals related to the misuse of subsidies for operating renewable sources (such as speculative purchases of PV installations, the untraceable ownership of many of these facilities, non-transparent granting of licences for their operation, etc.), their environmental benefits have been overshadowed and their public image significantly damaged. Thus renewable sources of energy are discussed in the Czech Republic more in the context of economic and political machinations than in relation to environmental benefits. The relative under-representation of AD plants in this debate, is at least in part explained by the more complicated nature of their deployment. Unlike wind farms and PV farms, AD plants require (bulky) feedstock which means they need to be much more integrated with existing lands use activities and agricultural companies. This implies a higher likelihood of local ownership and beneficiaries, raising questions of how and where these plants can and should support the rural economy.

Given that the potential for utilising renewable energy is always spatially heterogeneous, and that 'blanket' support policies across a diverse rural landscape will invariably lead to spatially uneven uptake, it is important to recognise that the current status of deployment of renewable energy plants is a snapshot of a more complicated spatio-temporal diffusion process.

This paper aims to analyse the diffusion of agricultural AD plants across rural landscapes in the Czech Republic in the last decade. AD plants built to mainly utilise industrial or urban waste (e.g. food processing, domestic waste, sewage) are not included in our analysis, since these plants have very different locational characteristics from agricultural AD plants. More specifically the paper will assess where in the countryside AD plants have been built, vis a vis (1) natural conditions for agricultural activities, agricultural production statistics and land use change; and (2) the socio-economic parameters of the local area where these plants are situated.

2. The legal framework for renewable energy in the Czech Republic

Legislative and strategic arrangements are the elementary prerequisites for the development of renewable energy sources in most countries. In the Czech Republic, this legal framework consists of the three key acts. Act no. 458/2000 Coll., on the Conditions of Business and State Administration in Energy Industries (the Energy Act [20]), regulates state and business conditions in electro-energetics, the gas industry, and the heating industry. It also deals with electrical generation licences and ensures that the producers of electricity from renewable sources shall be preferentially connected to the transmission grid. Act no. 406/2000 Coll. on Energy Management regulates effective and careful consumption of energy and energy sources [21]. The significant landmark in the history of renewable sources in the Czech Republic was Act no. 180/2005 Coll. on the promotion of electrical production from renewable energy sources (Act on Promotion of Use of Renewable Sources [22]), which regulates, in accordance with Directive 2001/77/EC of the European Parliament, the method of promoting the production of electricity from renewable energy sources [23]. One of the targets set in it was a share of electricity to be generated from renewable sources amounting to 8% of gross electrical consumption in the Czech Republic by 2010, which was achieved due to the PV energy boom, and also the creation of conditions for the further increase of this share after 2010 (see above). This act also ensured that the producers of electricity from renewable sources who meet the requirements stipulated by the Energy Act shall be preferentially connected to the transmission system. The act further deals with purchase prices for electricity from renewable sources and green bonuses, which are annually announced by the Energy Regulatory Office (ERÚ). This act was replaced on January 31, 2013 by Act 165/2012 Coll. on promoted energy sources [24], amending the Act no. 180/2005 Coll [22]. This was in response to Directive 2009/28/EC [12] and the resulting National Action Plan for Renewable Sources of Energy in the Czech Republic [25]. One of its fundamental targets is a share of energy from renewable sources to amount to 13.5% of gross energy consumption in the Czech Republic by 2020, while “taking into consideration customer interests in minimizing the impacts of this promotion on energy prices for customers in the Czech Republic” (Article 1, Paragraph 2, Letter d of Act No.165/2012 Coll. [24]). Feed-in tariffs for renewable electricity are ultimately paid for by consumers, who have seen their bills going up significantly in recent years. It is a popular and hence also a political concern that this act is seeking to mitigate somewhat. The National Action Plan for Renewable Sources of Energy [25] quantifies the installed capacities of individual types of renewable sources to be achieved in each year in the period 2010 and 2020. When this annual target has been achieved, there is no legal duty to further support the installation and operation of new renewable sources by means of the feed-in tariffs or green bonuses.

There are two ways to support biogas production as a renewable energy source under the conditions of the Czech Republic, either by supporting the construction of AD plants or by securing purchase prices for electricity, possibly also by supporting combined heat and electrical production by means of guaranteed purchase prices and green bonuses (the so-called feed-in tariff). Support for biogas production by means of feed-in tariffs started in the Czech Republic in 2002. The program gets revised annually and is valid only for new installations in the given year; the purchase price from the earlier installed sources is valorised. Since 2006, when Act no. 180/2005 Coll [22]. came into force, a 15-year payback on investments in AD plant construction has been guaranteed. The guaranteed purchase prices for electricity and green bonuses for agricultural AD plants, which are shown in Fig. 1, have not experienced the significant dynamics seen in more controversial installations of PV energy (see above; for example 12 250 CZK until 2010), and from 2009 they were steady at 4120 CZK per 1 MW of electricity (1 US dollar equals 24 Czech Crowns). Since 2012 support has been gradually limited, firstly by the 2013 introduction of additional tightening conditions (e.g., an additional requirement to use at least 10% of heat produced in AD plants was introduced), followed by a reduction in support for plants with an installed capacity of over 550 MW. Since the beginning of 2014 all state support for newly constructed AD plants was halted (see Fig. 1).

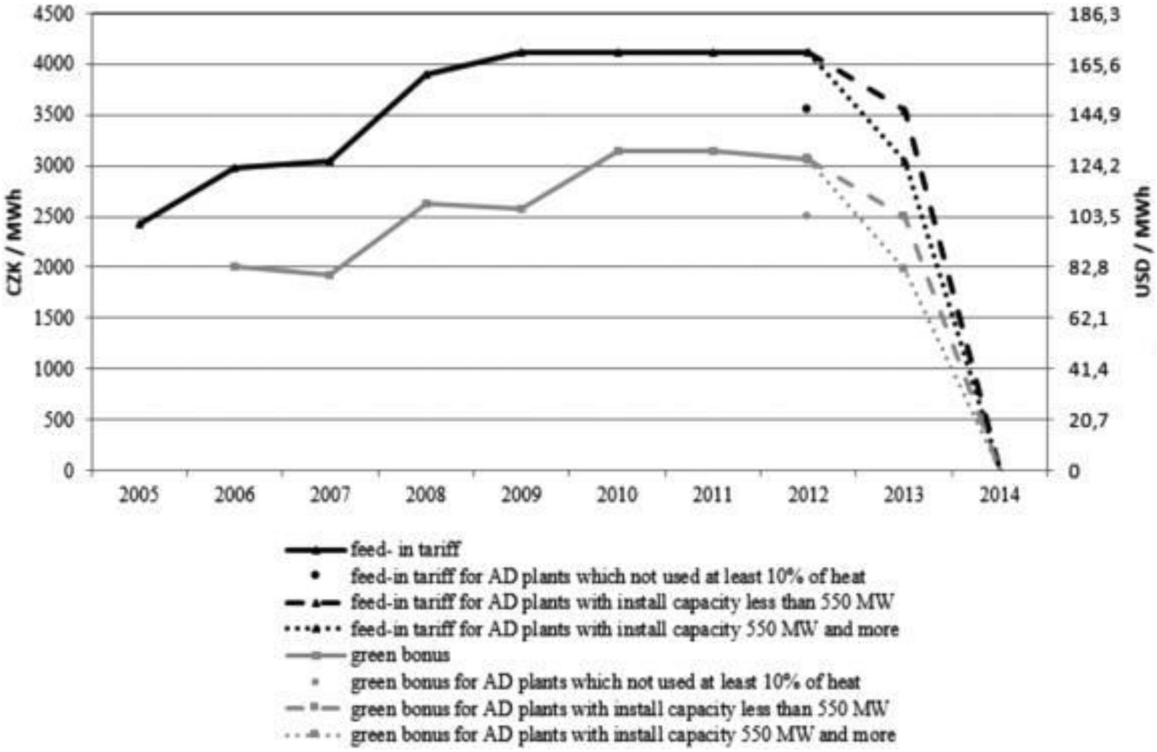

Fig. 1. Development of financial incentives for electricity generated by AD plants in the Czech Republic (2005–2014) (Source of data: Energy Regulatory Office (www.eru.cz), authors' processing).

The average investment costs for an agricultural AD plant in the Czech Republic is approximately 100 thousand CZK/kW of installed capacity (Dvořáček [26]). In the case of AD plants focused on waste processing, the cost varies between 200 and 250 thousand CZK/kW. Construction of the majority of AD plants in the Czech Republic were co-financed with public funds. The primary sources of public funds were the Rural Development Programme of the Czech Republic (Ministry of Agriculture) [27] and structural funds of the European Union - the Operational Programme Environment [28], Priority 3: Sustainable use of energy sources (Ministry of the Environment), and the Operational Programme Enterprise and Innovation [29] – Priority Axis 3: Effective Energy (Ministry of Industry and Trade). The importance of subsidies for the AD sector is apparent in Fig. 2, where the first significant increase in the number of plants can be seen in 2008, i.e., the period of implementation of approved projects for AD plant construction from the first call of the Rural Development Programme [27]. By 2012 178 projects had been supported at a total cost of 3.147 billion CZK (Diversification into non-agricultural activities III.1.1.b, Support for business creation and development III.1.2.b), with a maximum level of support between 40% and 60% of total construction cost according to the size of the enterprise (Rural Development Programme of the Czech Republic 2007–2013 [27]). The average amount of subsidy for one agricultural AD plant was 17.7 million CZK. The Operational Programme Environment [28] supported 6 projects at a total cost of 142 million CZK, and the Operational Programme Enterprise and Innovation [29] supported 35 projects at a total cost of 520 million CZK (including both agricultural and waste AD plants). All of the above amounted to a total of more than 3.8 billion CZK of state support for the AD sector, the majority of which was invested in agricultural AD plants; in the case of other types of AD plants, such subsidies are much less common. As a consequence of the above-mentioned huge support for both the construction and the operation of AD plants, their number has dramatically increased since 2011. The total number of these facilities on Czech territory now exceeds 500 (300 of them are agricultural AD plants) (see Fig. 2), but with the halt to further state support in 2014, this expansion phase has now ended. Fig. 3 displays the spatial distribution of various types of AD plants in the Czech Republic.

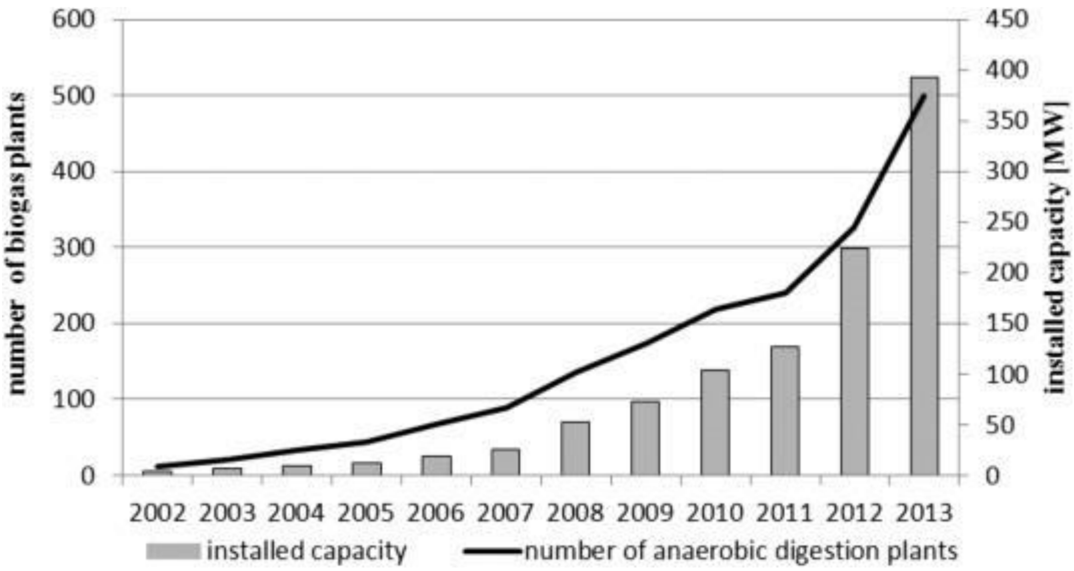

Fig. 2. Cummulative development of the biogas sector in the Czech Republic, including both urban and rural AD plants (2002–2013) (Source of data: Energy Regulatory Office (www.eru.cz).

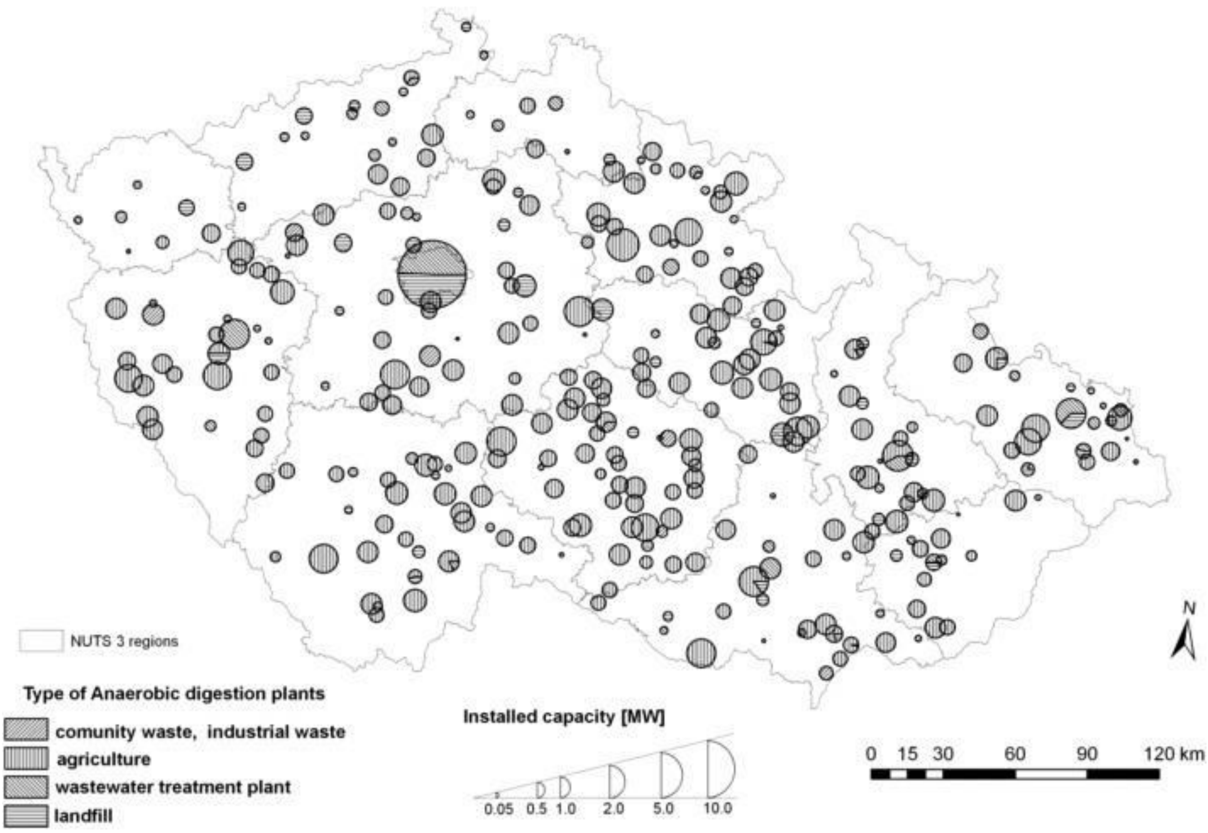

Fig. 3. Spatial distribution of various types of AD plants in the Czech Republic (2013) (Source of data: Energy Regulatory Office (www.eru.cz), Czech Biogas Association (www.czba.cz), authors' processing).

3. Agricultural AD plants in context; agrarian change in the Czech Republic

Agricultural AD plants process purpose-grown vegetable biomass (green maize, grass, perennial fodder plants, crop residues etc.) and waste of animal husbandry (cow manure, pig slurry, etc.). Stabilized residue (digestate) can be used as fertilizer after the fermentation process (Marada et al. [30]). Since agricultural AD plants process specific agricultural products, be they of plant or animal origin, whose production is spatially rooted in different natural conditions, it can be stressed that the location of agricultural AD plants is highly dependent on this production, especially since these products have a low value/weight ratio, making them rather expensive to transport (mathematical models of this dependence were recently reviewed in Balaman and Selim [31]; Kythreotou et al. [32]; Neiva de Figueiredo and Mayerle [33]).

Technological advancement over time, tends to increase total demand for energy. Agriculture is not an exception to these developmental trajectories. Contemporary consumption of heating and electric energy in the Czech agricultural sector amounts to some 4955 TJ per year (2011) according to data from the Czech Statistical Office, and this value as recalculated per agricultural hectare increases slightly every year. Moreover, growing farm energy bills have affected the prices of agricultural products in the Czech Republic, making them less competitive in comparison with agricultural imports (e.g. from other EU states). This has resulted in a decrease in the food self-sufficiency of the Czech Republic, raising concerns about the decreasing quality of food available for low-budget consumers (see Pinstrup-Andersen [34]).

In the late 1980s, more than 550 000 people found their jobs in Czech agriculture. This figure has now dropped to around 100 000, which is only 2.6% of the economically active population. A very similar trend can found in the case of the changing share of agriculture in the gross value added generated in the economy of the Czech Republic; it has dropped from 3% around the beginning of the new millennium, to 1.3% today. But agriculture in the Czech Republic has changed significantly not only in its extent but also in its structure. From the long-term perspective, the number (and thus importance) of livestock breeding operations has been systematically declining in favour of arable farming, whose products show a higher level of marketability on an internal market saturated with cheaper imports (Svobodová [35]). In the last two decades the extent of agricultural land within the Czech Republic has been reduced by 60 000 ha, the formerly very high share of arable land in agricultural land has slightly decreased (71%), and three fifths of cattle have disappeared (Věžník et al. [36]). During the course of the last decade, the number of pigs bred was halved (Věžník and Konečný [37]). The loss of livestock has direct consequences for the development of the agricultural AD sector; there are now far fewer opportunities to utilise animal waste as a feedstock. If we focus on arable farming, traditional crops like potatoes have been replaced on a large scale by oilseed rape, which has become the second most common plant in the agriculture of the Czech Republic (cultivated on more than 400 000 ha). Diversification trends in the economic activities of agricultural farms showed significant development both in agricultural activities (e.g., growing alternative crops and organic farming, with more than 4000 farms and 12% of total agricultural land in 2013) and non-agricultural activities (e.g., agritourism, and on-site processing and sales of agricultural products – Konečný [38]). A dramatic increase in agricultural subsidies after 2004 as a consequence of the implementation of the EU Common Agricultural Policy in the Czech Republic gradually increased the profitability of the whole agricultural sector, and thus also the ability of farmers to make investments in machinery or technology is much higher than before EU accession.

Energy dependence on fossil fuels is another issue making the agricultural sector vulnerable to global energy market changes. As Weiland [39], Pöschl et al. [40] or Lupp et al. [41] point out, responses to climate change warnings can be found in the production of renewable energy by farmers. AD plants fall into the category of facilities for renewable production that should, theoretically, be perceived by the public as less controversial, since they create not only an alternative source of income for farmers (Yiridoe et al. [42]) but are also a potential vehicle for rural development (Revelle [43]; Martinat et al. [44]; Kostevšek [45]; Warren [46]), by using the waste heat energy released by AD plants for heating local households, farms, etc. Many controversies are linked to the location of such AD plants, however, and to the use of dedicated (food) crops as feedstock for energy production (Lupp et al. [41]; Upham [47]; Jørgensen and Andersen [48]). The specifics of the spatial diffusion of AD plants in urban and rural space are commented on in studies by Barnett [49] and Daxiong et al. [50], who discuss the crucial role of state support in the initial stages of development in the AD sector. As an important topic widely discussed in the literature on renewable energy, public acceptance of such facilities is identified as a crucial point on household, municipal, regional, and national levels (Frantál and Kunc [51]; Jian [52]; Musall and Kuik [53]).

4. Methods

Data on individual agricultural AD plants (their locations, installed capacities, years of licence granting) was gathered from the open on-line sources of the Energy Regulatory Office of the Czech Republic (www.eru.cz), yielding a total of 317 operational AD plants (2013 figures). Agricultural AD plants are, in the Czech Republic, usually located within larger agricultural farms, and process agricultural crops and wastes for energy production. Analysis of spatial consequences of distribution of agricultural AD plants and its development has been carried out at three levels: (1) spatio-temporal diffusion and distribution of agricultural AD plants, (2) links between the location of agricultural AD plants and natural and agricultural conditions, and (3) links between the location of agricultural AD plants and socio-economic conditions.

4.1. Spatio-temporal diffusion and distribution of agricultural AD plants

Due to the fact that, from the spatial point of view, agricultural AD plants can be regarded as points located in the coordinate system, spatial indices, point pattern, and spatial autocorrelation were progressively assessed (Robinson, [54]). Series of spatial indices (the Lorenz Curve and the Gini Coefficient) were employed as the basic indicators for evaluating the spatio-temporal diffusion of agricultural AD plants (the Lorenz Curve shows cumulative distribution of given phenomena; the Gini Coefficient represents its dispersion). The indices were supplemented by series point pattern calculations. As the method, the Nearest-Neighbour Analysis was applied. For these calculations data on agricultural AD plants for the period 2002–2012 was used. The spatial structure of their distribution was assessed for the year 2012. We tried to reveal potential violation of supposed randomness in spatial distribution of AD as shown in Fig. 3. Two approaches were adopted. First the Global Moran's I was computed. Global Moran's I is variation of Pearson correlation coefficient used to test presence of autocorrelation in spatial point data. If Global Moran's I is statistically significant we can refused null hypothesis that the point are distributed randomly. Subsequently Anselin Local Moran's I method was used to identify if neighbouring regions show alike high or low values in one variable – here it is the question of installed capacity. The result of this analysis is commonly showed in maps with highlighted regions forming spatial clusters of high-high or low-low regions (Chun and Griffith [55]).

4.2. Links between the location of agricultural AD plants and natural and agricultural conditions

For an evaluation of the impact of natural and agricultural conditions on the non-randomness of the distribution of agricultural AD plants, it was necessary with respect to the specifics of available data to proceed by dividing the whole procedure into several steps. In the first instance general conditions for agriculture were evaluated. The general conditions for agriculture represent complex assumptions about the operation of agriculture in given conditions. This data was gathered for the whole area of the Czech Republic at the territorial level of individual cadastral units (more than 13 000 territorial units altogether). This data enabled the evaluation of the location of given agricultural AD plants using the general conditions for agriculture of the given cadastral unit where each plant is located. Agricultural conditions of given locations are represented by types of less favourable areas (LFA) and by types of areas of agricultural production (AAP). The less favourable areas (LFA) are areas with worse conditions for the operation of agriculture, where intensive subsidies from the Common

Agricultural Policy of the European Union are targeted. The less favourable areas (LFA) were defined on the basis of the Directive of the Government of the Czech Republic no. 75/2007 [56], and are divided into mountain area types (MA, MB), other/sub-mountain area types (OA, OB), and specific area types (SA, SB). The areas of agricultural production (AAP) were also defined at the level of individual cadastral units of the Czech Republic, and characterise the agricultural conditions of a given area from the point of view of its soil and climatic conditions. On the basis of the Regulation of the Ministry of the Treasury of the Czech Republic no. 178/1994 [57] and the Regulation of the Ministry of Agriculture of the Czech Republic no. 215/1995 [58], five basic areas of agricultural production were delimited (Corn AAP, Sugar beet AAP, Grain AAP, Potato AAP, and Fodder crop AAP), along with 21 subtypes within the basic areas. In our evaluation, only the five basic areas of agricultural production were taken into account.

The potential difference between the numbers of agricultural AD plants located in cadastral areas with individual types of LFA and AAP and the expected value of these numbers was also investigated. The numbers of agricultural AD plants were taken from 2012 data. The expected values were calculated as the share of agricultural AD plants that should be located in individual types of LFA and AAP and then compared to the share of area of individual types of LFA and AAP on the area of the Czech Republic. The difference was tested by the Chi-squared goodness-of-fit test (Robinson [54]).

In the next step, spatial links between the location of agricultural AD plants and changes in agricultural production in their surroundings (here districts – NUTS4 level) were tested. Data on agricultural production that originates in agricultural censuses (Agrocenzus 2005 [59], Agrocenzus 2010 [60]) were gathered for the year 2005, in the period before the boom in AD plant development, and for year 2010, the year for which the most recent data were available. Utilisation of the set of data at the district level (77 units in the Czech Republic) was necessitated by the unavailability of data for lower hierarchical levels, such as the cadastral. The average acreage of individual districts oscillates around 100 000 ha. Both the state of agricultural production in 2010 in individual districts of the Czech Republic and changes in agricultural production in the period 2005–2010 were evaluated. The tested model was fed with these variables: sowing areas of wheat, rye, barley, oat, maize, sugar beet, oilseed rape, sunflower, green maize, fodder crops, potatoes, and the number of cattle, pigs, and poultry heads. The impact of the production of these agricultural products on the size of the total installed capacity of all agricultural AD plants in individual districts was tested. The aim of the testing was to identify a limited number of different predictors. This is the reason why multiple linear regression was employed (Nusair and Hua [61]) by using the forward selection method for independent variables. The first run of forward selection was performed. Then the data was purged of outliers. Consequently, the process of forward selection was repeated. The model was assessed based on partial regression graphs and partial residual graphs, and the method was assessed by means of the F-test of importance of a regression model and Adjusted R^2 (Meloun and Militký [62], Navrátil et al. [63]).

The third category of data that was tested to reveal the influence of natural and agricultural conditions on the location of agricultural AD plants were land-use changes. With respect to data availability for spatial units in the Czech Republic, land-use data for the years 2005 and 2012 were evaluated at the level of municipalities (6253 units, NUTS5 level). On the basis of Czech Statistical Office data (spatial analytical documents) for all municipalities in the Czech Republic, the following variables were calculated: changes in the share of arable land on agricultural land in a municipality, changes in the share of permanent grasslands on agricultural land in a municipality, and changes in the share of agricultural land in the total area of a municipality. Firstly, the average value of these changes in municipalities was calculated for the Czech Republic as a whole, which value was considered in further analyses as the average value of land-use change in the basic set of municipalities. As the next step, municipalities where agricultural AD plants are located were assessed independently. Then potential differences between the average value of land-use changes in municipalities with agricultural AD plants and the average for the Czech Republic as whole were tested by means of the one-sample *t*-test method (Quinn and Keough [64]).

4.3. Links between the location of agricultural AD plants and socio-economic conditions

Due to the nature of the raw material that they process, agricultural AD plants are primarily located in rural areas. Since plenty of previous studies have proved that the countryside of the Czech Republic is a highly diverse space (e.g. Perlín et al. [65]), and the previous results of our analyses also indicated a relatively high diversity of location factors for agricultural AD plants, we tried to evaluate the power of predictors of individual variables used in the typology of rural space and in the location of agricultural AD plants as well. Based on the available data, partial indicators for four factors at the level of municipalities were followed – size, population growth, human potential, and housing. Within the mentioned factors a set of other indicators for individual municipalities was analysed: population number (2013), net migration (2012), share of native population (2011, in %), participation in elections (2010), population change (2005–2013, in %), share of houses built or reconstructed (2001–2011, in %), share of population with maximum primary education (2011, in %), share of the economically active population in agriculture, forestry, and fisheries (2011, in %), natural increase (2012), unemployment rate (2011, in %), age index (2012), and the share of the economically active population in accommodation, food services, and hospitality (2011, in %). The dependence of the location of agricultural AD plants on the variables of the four mentioned factors was analysed by logistic regression of the binary variable (the presence of agricultural AD plants in the municipality) with PROBIT link. All municipalities of the Czech Republic entered the tested model. Each regression coefficient (i.e. its difference from zero value) was tested by Wald statistics. Its importance was assessed then by standard error (s.e.) of this estimation and significance (= the p-value) of the Wald test. The statistical importance of the whole model was tested by means of the Hosmer-Lemeshow test of goodness of fit (Hosmer and Lemeshow [66]). No outliers were removed.

5. Results and discussion

As already stated above, the spatial coherences of biogas production and the location of agricultural AD plants in the Czech Republic were assessed on three levels: 1) the spatio-temporal diffusion of plants, 2) links between the location of plants and natural and agricultural conditions, and 3) links between the location of plants and socio-economic conditions.

5.1. Spatio-temporal diffusion and distribution of agricultural AD plants

As the first step, the spatio-temporal aspects of the location and diffusion of agricultural AD plants on the territory of the Czech Republic were evaluated. The basic spatial indices (the Lorenz Curve and the Gini Coefficient) were employed to understand this problem (see Fig. 4). On the basis of this analysis three phases of diffusion of agricultural AD plants in the Czech Republic were identified, corresponding to the classical model of spatial diffusion (Hägerstrand [67]; Haggett [68]). While the high values of the Gini Coefficient for years 2002–2006 match the Initial Deployment Phase, the following period (2008–2009) is typical in its sharp decrease in the value; this period can be marked as an Expansion Phase (boom of the sector). Since 2009 the Filling Phase occurs, which is typified by a low annual decrease of values of the Gini Coefficient. If we use Rodgers' [69]) spatio-temporal typology of innovation diffusion, then the introductory period (until 2006) corresponds to the phase of innovators and early adopters, the period of 2008–2009 matches to the early majority, and the period after 2009 could be linked to the phases of late majority and laggers. A very similar structure of spatial development of the location of agricultural AD plants has been shown in the location of studied facilities in other parts of Europe (Madlener and Schmid [70]; Madlener et al. [71]; Sorda et al. [72]; Theofanous et al. [73]). It can be said that the crucial driving force behind the diffusion of this technology is the supportive financial incentives in individual countries, which vary in both type and intensity of incentive. The results of the analysis undertaken were proved by the Nearest-Neighbour Analysis, which confirmed a gradual spatial tendency to create spatial clusters of agricultural AD plants (statistically significantly since 2011) (the decreasing value of R - see Fig. 5).

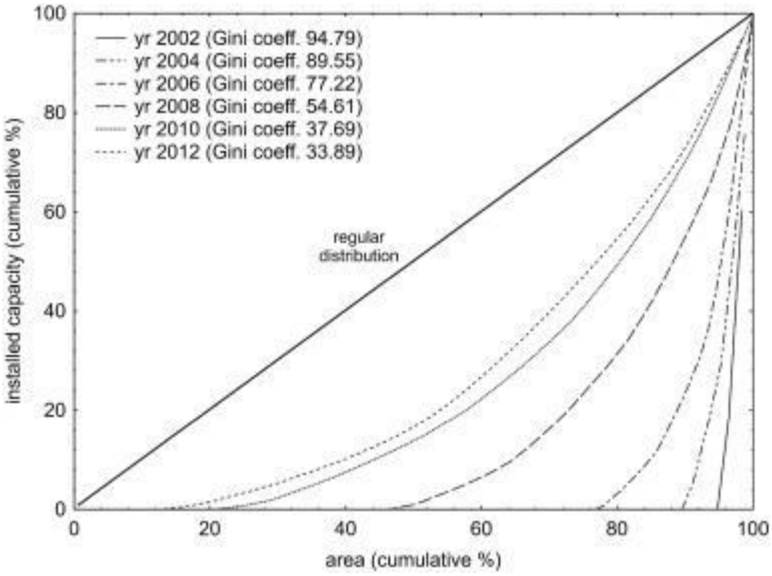

Fig. 4. The Lorenz curves of the total installed capacity of AD plants for years 2002–2012, Gini coefficients are presented in brackets in the upper left (Source of data: Energy Regulatory Office (www.eru.cz), authors' processing).

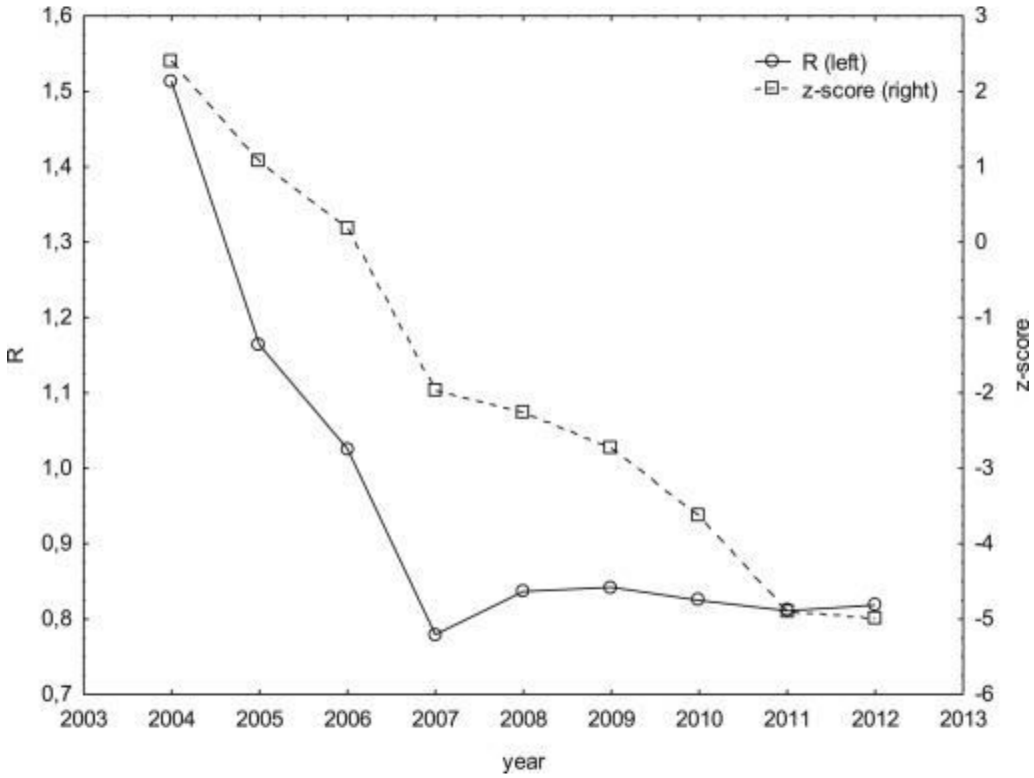

Fig. 5. Development of values of the Nearest-Neighbour Analysis and Z-score for agricultural AD plants in the Czech Republic in period 2004–2012 (Source of data: Energy Regulatory Office (www.eru.cz), authors' processing).

The spatial coherences of the location of agricultural AD plants were further explored by means of spatial autocorrelation methods. The possible violation of statistical spatial independence was tested by using Moran's spatial autocorrelation at the level of districts for the distribution of plants in 2012. The violation of the spatial independence of occurrence of agricultural AD plants has been proved (Moran‘s I = 0.28896, z-score = 3.4), which for given degrees of freedom causes level of statistical significance (p = 0.000673). The value achieved (0.28) is not so high, but still highly significant. Therefore it is obvious that for the location of agricultural AD plants coherences do exist, leading to their non-random distribution at the level of districts.

As we already know from the analyses described above, within the territory of the Czech Republic neighbouring districts occur where high and low numbers of agricultural AD plants are located. To enable the spatial identification of these particular clusters, the Anselin Local Moran's I method was employed. Statistically important locations of clusters with high values of installed capacity have been identified in the sub-mountain areas of the western and southern Bohemian-Moravian Highlands and in the sub-mountain areas of the Eagle Mountains (in the eastern part of Bohemia), while on the contrary low values are represented by a cluster in north-west Bohemia where region Most is the core of this cluster surrounded by other regions with low installed capacity – Chomutov, Louny, and Teplice (see Fig. 6). This result show us in which regions is real high and low spatial concentration of AD installed capacity presented in point pattern in Fig. 3. We observed that regions with the highest concentration of agricultural AD plants (in number of plants and in their installed capacity) coincide with the distribution of the first experimental AD plants which have been in operation since the 1970s. It can be hypothesised that this early experience has helped to create regional familiarity and support for the increased adoption of AD plants among local farmers (for more on the topic of acceptance of renewable sources, see e.g. Frantál and Kunc [51]).

Fig. 6. Location of cluster of regions with high (crosshatch) and low (ordered simple) occurrence of agricultural AD plants (based on application of the Anselin Local Moran's I method) (Source of data: Energy Regulatory Office (www.eru.cz), authors' processing).

By means of comparison of real annual amount of electricity generated by AD plants and theoretical amount of electricity (installed capacities), recalculated for number of hours per year (see Table 1), it is possible to identify three different historic phases. Whilst in the pre-boom period of years 2008–2010 a 60% effectiveness of operation of AD plants in the Czech Republic was typical, during later period (2011–2012) this ratio was improved to circa 75%. At the height of the AD plants development boom (2013) in term of both numbers of plants and their installed capacities, plant performance actually dropped back to 65%, which might be caused by saturation of the energy market. The significant growth of renewable energy as a share of the total electricity generation (11,6% in 2014), could not have been achieved without the contributions of the AD sector, which now represents almost one quarter of all renewable electricity generated in 2014. Nowadays, almost 3% of total electricity generated in the Czech Republic is produced by the AD sector, which is ten times more than in 2008. On the basis of these overall numbers, the AD sector has been a clear success story, but our analysis reveals a more nuanced picture, with the sector performing not as well as it could on environmental grounds, and not equally across different rural landscapes. Nevertheless, as mentioned above, such development has been accompanied by unintended environmental consequences and might be perceived as unused potential (from the point of view of both inputs and outputs).

Table 1. The development of AD sector and its efficiency in the Czech Republic (2008–2013).

	2008	2009	2010	2011	2012	2013
Generation of biogas (GWh)	246.8	404.9	590.8	868.2	1 406.4	2 243.3
Installed capacities of biogas stations (MWh)	52.4	73.2	103.3	127.0	224.2	392.4
Coefficient of annual effectiveness (%)	53.4	63.2	65.3	78.0	71.4	65.3
Share of renewable sources on total electricity generation (%)	4.9	6.3	7.5	8.9	10.1	11.6
Share of biogas on renewable sources (%)	6.0	7.8	9.2	11.1	15.9	22.1
Share of biogas on total electricity generation (%)	0.3	0.5	0.7	1.0	1.6	2.6

Note: Coefficient of annual effectiveness – share of annual generation of biogas (in MWh)/installed capacities (in MWh) multiplied by annual number of effective hours (8760 h, 8784 h for leap-years) (in %). Source: Energy Regulatory Office (www.eru.cz), authors' processing.

5.2. Links between the location of agricultural AD plants and natural and agricultural conditions

As the first step, potential links between the above-identified differentiations in the location of agricultural AD plants and general agricultural conditions were tested. In the case of less favourable areas for farming (LFA), the hypothesis of an absence of differences in real and theoretical locations of agricultural AD plants in types of LFA areas can be rejected (Chi-Square = 25.02401; d.f. = 5; p = 0.000138; see Table 2). Thus, agricultural AD plants are generally concentrated in the areas outside of LFA and to the other/sub-mountain LFA areas with worse natural conditions for farming (OA, OB). These facilities are not located in the mountain type of LFA areas (MA, MB). This leads us to assumption that agricultural AD plants are particularly located into two mutually distinct areas – in areas with sub-mountain conditions (OA, OB) and in the areas suitable for arable agriculture (outside of LFA).

Table 2. Observed and expected numbers of agricultural AD plants in different types of less favoured areas (LFAs) in the Czech Republic (pairs in italics are of highest statistical significance).

	Out of area of LFA	Mountain type of LFA (MA)	Mountain type of LFA (MB)	Other/sub-mountain type of LFA (OA)	Other/sub-mountain type of LFA (OB)	Specific type of LFA (S)
Observed	*101*	*12*	2	*61*	*20*	11
Expected	*89*	*36*	3	*49*	*14*	16

Source of data: Czech Statistical Office (www.czso.cz), Energy Regulatory Office (www.eru.cz), authors' processing.

These findings confirm another step that was carried out, namely the analysis of the location of AD plants within individual areas of agricultural production, which were delimited on basis of soil quality and climate of given areas (AAP, see above). Also in this case, a statistically significant difference between the real and theoretical distribution of agricultural AD plants was revealed (Chi-Square = 25.013; d.f. = 4; p = 0.000050; see Table 3). Plants are primarily located outside of areas of fodder crop production (i.e. outside mountain areas). On the contrary, a much stronger clustering of plants was detected in areas of potato production (in sub-mountain areas). In areas of high grain and sugar beet production, the number of digestion plants corresponds to the theoretical distribution, but in areas of maize production locations of agricultural AD plants are much more frequent. Thus, agricultural AD plants can be found in the Czech Republic in sub-mountain areas (the western and southern parts of the Bohemian-Moravian Highlands and in the sub-mountain areas of the Eagle Mountains) and also in highly productive areas with good soil fertility in the south of Moravia. Such distribution of agricultural AD plants is significantly affected by general development of Czech agriculture after the EU accession, when farmers in sub-mountain areas are constantly looking for alternative ways of income (and find it in operation of AD plants) due to worsen natural conditions for traditional farming, while in areas with good soil fertility agricultural AD plants are more focused on processing of agricultural wastes (and less significantly on processing of purpose-grown maize). Generally is might be stated that spatial distribution of agricultural AD plants significantly contributes to economic stabilisation of farming in various natural conditions. As is discussed, bellow potential environmental benefits of operation of AD plants are rather disregarded.

Table 3. Observed and expected numbers of AD plants in agricultural production area (AAP) types in the Czech Republic (pairs in italics are of highest statistical significance).

	Area of agricultural production (corn AAP)	Area of agricultural production (sugar beet AAP)	Area of agricultural production (grain AAP)	Area of agricultural production (potatoes AAP)	Area of agricultural production (fodder crops AAP)
Observed	*10*	50	83	*56*	*8*
Expected	*6*	45	87	*40*	*29*

Source of data: Czech Statistical Office (www.czso.cz), Energy Regulatory Office (www.eru.cz), authors' processing.

Due to the important differences in the locations of agricultural AD plants previously identified in the context of types of less favourite areas (LFA) and of types of areas of agricultural production (AAP), it might also be assumed that differences could be detected in the case of agricultural production generated in the hinterland of digestion plants. This is why links to agricultural production were also tested; by means of the regression model (F (5.71) = 52.916; Standard Error of Estimate = 0.890). Results show that the extent of the installed capacity of agricultural AD plants is dependent upon the size of sowing areas of maize (installed capacity grows with growth of sowing areas), the size of sowing areas of fodder crops (installed capacity grows with growth of sowing areas), the growth of sowing areas of maize 2005–2010, and also on a low level of poultry breeding (see Table 4). These predictors explain 77.35% of the variability in the installed capacity of agricultural AD plants in individual districts of the Czech Republic. These findings are consistent with studies in Germany and Italy where high dependence of the location of agricultural AD plants on agricultural resources (especially maize production) has been identified (Pöschl et al. [74]; Zubaryeva et al. [75]). Statistical data on sowing areas of individual crops is only available at the district level, thus restricting us to perform more detailed spatial analysis. The available agricultural data does not allow us to distinguish between the primary use of maize for feeding cattle and that for energy. However, significant declines in cattle breeding and gradually increasing sowing areas of maize in given areas points towards a significant shift in the use of this crop in favour of energy processing. The environmental benefits that could arise from the utilisation of agricultural wastes, unused hay and grass, and bio waste of rural households as feedstock for AD plants are not realised in the Czech Republic where agricultural AD plants are almost exclusively run on purpose-grown agricultural crops. The decisions of farmers (as operators of agricultural AD plants) to feed their plants with green maize points at omissions in the supporting programs to stimulate the use of more environmentally beneficial feedstock and avoid direct competition with food or fodder crops. Energy usage of green maize is perceived by farmers as the most economically effective solution, since operation of digestion plants ensures a secure, stable, and highly profitable destination for cultivated crops. In response to the dramatic decreases in livestock breeding and the arrival of cheap imported food on the Czech market in the wake of EU accession, farmers have seized the funding for agricultural AD plants as an opportunity to continue with a highly productive mixed farming model of Czech agriculture, where the AD plant replaces the cow as a tool to process green maize into a higher value product. AD plants are thus embraced because they are more competitive than cows under the current subsidy arrangements, not because they provide opportunities to address local or global environmental problems. A similar energy-related productive shift in Czech agriculture can also be observed in the case of recent increases in the sowing areas of oilseed rape (a feedstock for biodiesel) at the expense of potato cultivation (Svobodová and Věžník [76]).

Table 4. Model of agricultural production statistics as predictors of AD installed capacity at the district level; b = the estimated value of regression coefficient; S.E. of b = Standard Error of b; t = *t*-test of statistical importance of the estimated value (with degrees of freedom in brackets); p = statistical significance of Wald test; n.s. = not statistically significant.

	b	S.E. of b	t(71)	p
Intercept	−0.0685	0.1934	−0.354	n.s.
Sowing areas of maize (2010)	0.0003	0.0001	2.894	<0.01
Sowing areas of fodder crops (2010)	0.0006	0.0001	4.704	<0.001
Change of sowing areas of maize (2010–2005)	0.0012	0.0003	4.561	<0.001
Changes in cattle breeding (2010–2005)	−0.0002	0.0000	−4.310	<0.001
Poultry breeding (2010)	−0.0000	0.0000	−2.486	<0.05

Source of data: Czech Statistical Office (www.czso.cz), Energy Regulatory Office (www.eru.cz), N.S. = not significant.

The changes to the agricultural use of the landscape in the context of the operation of agricultural AD plants are also related to changes in land use in the vicinity of the plants. Thus, while differences in the location of agricultural AD plants both from the point of view of their spatial diffusion and of agricultural production were identified above, now possible differences in land use changes in individual municipalities with agricultural AD plants were tested. The average change in the share of arable land in the total acreage of cadastral areas of the Czech Republic were compared to areas with agricultural AD plants (for the period 2005–2012). This decrease of share of arable land is statistically lower in cadastral areas with digestion plants than the average for the Czech Republic as a whole ($t = 3.460$; d.f = 206; $p < 0.001$). If we focus on average change in the share of permanent grassland against the total acreage of cadastral areas in given period (2005–2012), we find that increases of share of permanent grasslands are statistically lower in areas with agricultural AD plants than in the

Czech Republic as a whole ($t = 3.667$; d.f = 206; $p < 0.001$). This result is consistent with the previous findings of our analysis, which identified a lower decline in the share of arable land (arable land is most frequently converted to grasslands due to the support policies). In connection with the results of previous analyses, there appear also to be interesting results in the change of the share of agricultural land in the total acreage of cadastral areas. In the Czech Republic as a whole and in the municipalities with agricultural AD plants, the share of agricultural land in the area was lower, however in cadastral areas with the plants statistically more important decreases was measured ($t = 3.084$; d.f = 206; $p < 0.01$). In case of gardens, moderate increases in their share of cadastral area acreage were experienced, nevertheless significant differences between areas with and without the plants were now identified ($t = 0.293$; d.f = 206; $p > 0.05$).

It has been found that the operation of agricultural AD plants is related to changes in land use in the cadastral areas in which they are located. Agricultural AD plants can therefore usually be found in cadastral areas where agricultural land is decreasing more sharply than in the Czech Republic as a whole. However, the declines in arable land are surprisingly not so intensive. This may mean that due to the demand from operators of agricultural AD plants for crops grown in the vicinity of plants (mainly green maize) to be used as energy inputs, there are not such significant declines in arable land as in areas without plants. This is particularly interesting in light of the location of the majority of agricultural AD plants in areas of potato production (sub-mountain areas), where high decline in arable land is otherwise anticipated. In other words, it seems as though the agricultural AD plants in these sub-mountain areas play a positive role in slowing down the decline of arable land in the vicinity of the plant. Set against a regional benchmark of decline, the AD plant thus represents a localised relative intensification of agricultural land use.

5.3. Links between the location of agricultural AD plants and socio-economic conditions

This section focuses on the socio-economic characteristics of the municipalities where agricultural AD plants are located. Particular indicators (Table 5) were identified on the basis of relevant literature (Perlín et al. [65]). The resulting value of the Hosmer Lemeshow test is 7.0247 ($p = 0.5339$) for logistic regression of the binary variable (presence of agricultural AD plants in the municipality) with PROBIT link. Thus we fail to reject the null hypothesis that there is no difference between observed and model-predicted values, implying that the model's estimates fit the data to an acceptable level. Table 5 shows that the municipalities containing agricultural AD plants are characterised by a higher share of native population, lower participation in elections, higher decreases in population, a lower share of population with maximum educational level of the primary school, a higher share of employment in agriculture, forestry and fisheries, and a lower value of age index (share of population with age 65 and more years on young population with less than 15 years). The results of the analysis are of a highly diverse and mixed character, which means that municipalities with agricultural AD plants are hard to place in any pre-existing types of rural areas identified in the Czech Republic (Perlín et al. [65]). This could be due to the presence of agricultural AD plants in multiple types of countryside in the Czech Republic (see above), but also due to the short period for evaluation, during which significant differentiations of socio-economic conditions were not experienced. Despite the above-mentioned problems, the results obtained can be partially interpreted.

Table 5. Model of agricultural AD plants localization predictors (socio-economic indicators for the level of municipalities); S.E. = Standard Error of Estimate; Wald = Wald test of statistical importance of the estimated value; p = statistical significance of Wald test; n.s. = not statistically significant.

	Estimate	S.E.	Wald	p
Intercept	0.158	0.425	0.137	n.s.
Population number (2013)	0.001	0.001	0.835	n.s.
Net migration (2012)	−0.001	0.001	0.734	n.s.
Share of native people (2011, %)	0.015	0.004	13.858	<0.001
Participation in elections (2010)	−0.024	0.005	23.701	<0.001
Population change (2005–2013, %)	−0.008	0.004	4.683	<0.05
Share of houses built or reconstructed (2001–2011, %)	0.005	0.007	0.525	n.s.
Share of population with maximum primary education (2011, in %)	−0.050	0.010	23.969	<0.001
Share of economically active population in agriculture, forestry and fisheries (2011, %)	0.0196	0.005	17.776	<0.001
Natural population increase (2012)	−0.001	0.002	0.030	n.s.
Unemployment rate (2011, %)	−0.015	0.008	3.798	n.s.
Age index (2012)	−0.002	0.001	4.819	<0.05
Share of economically active population in accommodation and food services and hospitality (2011, %)	−0.003	0.014	0.042	n.s.

Source of data: Czech Statistical Office (www.czso.cz), Energy Regulatory Office (www.eru.cz), authors' processing.

We can say that the majority of agricultural AD plants are located in the non-development neighbourhood countryside type (the Bohemian-Moravian Highland) or in ambivalent types of rural areas of the Czech Republic (north of Czech-Moravian border). As already stated above, these areas are hardly definable from the point of view of their socio-economic development. Nevertheless, agricultural AD plants are also partly located in other specific types, such as equipped Moravian countryside, which overlaps with the above-mentioned area of sugar beet production. Thus, a potentially important position can be seen in agricultural resources, which are highly diversified according to local natural conditions for the operation of agriculture. In the non-development type of countryside, crops for digestion plants are grown on otherwise unprofitable land, while in areas of sugar beer production, agricultural waste is increasingly processed due to the higher profitability of the classic crops grown there. The effect of substitution of sources is obvious here. There is no doubt that agricultural AD plants are generally located in the countryside (cf., the high employment in agriculture, forestry and fisheries – Table 5) (Getis et al. [77]). Other common socio-economic characteristic of municipalities with agricultural AD plants are their higher traditional character (higher level of native population), not so high level of involvement in public affairs (lower participation in elections – as evidence for case of wind energy by study of Frantál [78]), and higher intensity of depopulation of these areas (population decreases between 2005 and 2012). On the contrary, from the point of view of age structure, such municipalities are in general younger and evidence much better age structure than the depopulation type of Czech countryside (Perlín et al. [65]) – the age index was found in the case of municipalities with plants to be lower than in municipalities without these facilities. This could be interpreted in the context of the higher level of traditionalism in these areas (with a generally higher shares of believers than in other area of the Czech Republic), where larger families with more children are more frequent.

To sum up, agricultural AD plants are usually located in the Czech Republic in more problematic areas but their location avoids the rural areas with the heaviest problems (the northern parts of Bohemia and border areas in general). On the other hand, they are clearly located less in development than in non-development types of Czech countryside. This in turn means that a certain link between the locations of agricultural AD plants and the values of socio-economic indicators does exist but it is more mediated. It seems that from the point of view of the location of agricultural AD plants, agricultural production is of primary importance; socio-economic indicators are influential secondarily.

6. Conclusion

The aim of the paper was to analyse the diffusion of agricultural AD plants in the Czech Republic in the last decade and to examine the natural, agricultural conditions for farming (less favourable areas, areas of agricultural production), as well as socio-economic parameters of the areas where such facilities are in operation. Statistically significant correlations were found, illustrating that there are important spatial patterns in the adoption of agricultural AD plants. Rather than being built 'anywhere suitable' for energy crop production, our paper demonstrates that the adoption of AD plants is clearly sensitive to spatially heterogeneous processes of agrarian change and restructuring of the agricultural sector. This kind of analysis is of relevance for any country that is seeking to promote rural biogas production, helping to reveal locations with (much) higher chance of adoption, possible clustering effects due to neighbourhood networks and localised familiarity with the technology (see e.g. Van der Horst 2011 [79]). The findings reported in this paper are also novel given the Central and Eastern European context (under-represented in the academic literature), where land is relatively abundant, agriculture was fundamentally restructured after the fall of communism, and where the renewable energy sector has grown considerably under supportive EU policies and national schemes. In short, there is clear scope for greater future use of the human geography research methods utilised in the paper, which combine social and environmental analysis, to study the co-development of agricultural and renewable energy production across diverse rural landscapes (Frantál et al., 2014 [80] or Navrátil et al. [81]).

To recap our empirical findings, the agricultural AD plants in the Czech Republic are significantly localised in areas characterised by former potato production, which is recently strongly replaced by green maize production; the size of their installed capacities is dependent on the size of the sowing areas of green maize (their performance grows with increases in their sowing area) and on the size of the areas sown with fodder crops. The location of agricultural AD plants influences the land use of municipalities in which they are located. In these municipalities, agricultural land decreases significantly, and smaller increases in permanent grasslands are evident, while decreases in arable land are not as strong as in other geographical areas where AD plants are absent. Analysis of socioeconomic data indicates that municipalities with AD plants are characterised by a local population that is comparatively more traditional, more populated by people who live at one place for whole life, more disengaged from public affairs and more affected by depopulation.

From the perspective of renewable energy policy, we can conclude that despite the large number of AD plants built in the Czech Republic, the supporting frameworks and subsidies for agricultural AD plants are failing to some extent to deliver their formal objectives (e.g. waste biomass has a lower carbon footprint than dedicated energy crops; much of the heat is not being utilised; see Van der Horst 2005 [82] for examples of different energy and rural policy objectives in case of UK). Subsidies for the operation of these plants serve more as a mediated support for particular forms of agricultural production (e.g. AD plants replacing cows as the key consumers of locally grown green maize), and consequently as a support for further production activities of farmers, rather than as support for the transition towards a low carbon and more energy self-sufficient or energy secure countryside. State support for biomass energy (including rural AD plants), is typically justified through a range of social, economic and environmental objectives. This (wish) list may be internally incoherent as it is unlikely that all these objectives can be maximised together. This paper has demonstrated the use of geographical tools to examine more closely which objectives are better served than others, and thus reveal the implicit policy bias in the selection of support mechanisms for AD plants. Main principles and aims of renewable energy policy of the Czech Republic are principally similar to the EU renewable energy policies, but settings of support for renewable energy has been selected more with respect to achieve agreed EU targets for 2020 (thus technocratically) then with respect to real environmental benefits. Thus, gradual tightening and elimination of apparent mistakes (like limited use of heat) is good step forward, but full suspension of support in 2014 can assessed as mistake. Wise support for development of renewable energies based more on environmental targets would be very useful. Good way out from this problem could be to focus more on energy processing of wastes (agricultural, households etc.), whose landfilling is expected to be reduced in near future.

It is quite a difficult challenge to evaluate effectiveness of the operation of AD plants. Because of unavailability of data on individual, local or even regional level about generation of electricity in the Czech Republic we are made to use sectoral data for whole country. By means of comparison of real annual amount of electricity generated by AD plants and theoretical amount of electricity (installed capacities), recalculated for number of hours per year (see Table 1), it is possible to identify three different historic phases. Whilst in the pre-boom period of years 2008–2010 a 60% effectiveness of operation of AD plants in the Czech Republic was typical, during later period (2011–2012) this ratio was improved to circa 75%.

Since financial incentives for building of new AD plants in the Czech Republic has been in 2014 stopped, this paper is primarily based on ex-post evaluation of their consequences, rather than on future scenarios of their development. On the other hand, it will be undoubtedly interesting to observe future development of agricultural AD plants and its consequences for agricultural and rural development in the Czech Republic in no so incentives-rich times.

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