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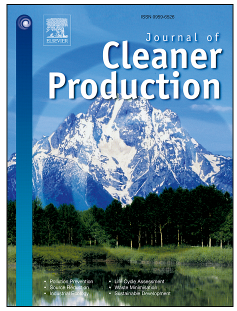

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Renewable Energy Recovery Potential towards Sustainable Cattle Manure Management in Buenos Aires Province: Site Selection based on GIS Spatial Analysis and Statistics

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ABSTRACT

The rise in GHG emissions associated with the combustion of fossil fuels for electricity generation, coupled with energy security issues and the likely future scarcity of non-renewable resources, has called the attention to explore the potential of renewable and clean energy alternatives. Argentina has enjoyed a rapid economic growth after the 2002 financial crisis. However, this economic recovery has caused a huge increase in energy demand that already surpassed the domestic production capacity and pushed the country to import natural gas for electricity production. As a consequence, currently more than two thirds of electricity is generated from natural gas and other fossil fuels that are causing not only an increase in GHG emissions but other pollutants as well. Taking advantage of its stunning cattle sector, this research explores the potential of biogas production in Argentina using Buenos Aires province, the province with the largest inventory, as a case study. Through the use of GIS suitability analysis, the study first identifies the potential sites for the location of the biogas plants based on geographical, environmental and socio-economic criteria. The study couples these findings with the selection and identification of optimal sites through the use of spatial statistical analysis and taking into account cattle farm size and economically feasible transportation distances. In this step, the study proposes three different scenarios that range from onsite plants for large-scale farms to centralized biogas plants for small-scale

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and mid-scale farms. The results of the study suggest that by using only 1.5% of the manure produced in the province, it could be possible to meet not only the cattle farms electricity demand but also up to 2.06 % of the demand in the province. These results open up a great opportunity for the country since it could be possible to not only address energy security issues with domestic resources, but at the same time to provide environmental benefits in a sustainable way.

Keywords: Biogas; GIS; spatial statistics; Buenos Aires Province; cattle manure; renewable energy

1. Introduction

In 2001-02 Argentina experienced one of its worst economic crises. A combination of factors including its high public and external debt burden and failed polices triggered inflation, unemployment and poverty to levels not seen before. The GDP decreased around 62% between the years 2001 and 2002 (World Bank Statistics a, 2016). To address this crisis new economic measures were taken (among them, a devaluation of the domestic currency that boosted the exports, creating a more favorable scenario for the industry) that helped the country's economy recovery and since then, Argentina has enjoyed a rapid economic growth. However, this economic recovery has caused a huge increase in energy demand (especially electricity) that already surpassed the domestic production capacity and pushed the country to import natural gas (NG) for electricity production. Currently more than two thirds of electricity is generated from NG and other fossil fuels (CAMESSA, 2014). Under the current situation the country faces two main socio-economic and environmental problems i.e. energy security, since the availability of domestic energy resources is extremely important for the economy and the increase in GHG and pollutant emissions associated with combustion of fossil fuels. In order to address this difficult challenge, the government has put special attention on promoting energy savings by cutting subsidies, securing the supply of natural gas from neighboring and overseas countries, and to a lesser extent promoting renewable energy (ENARSA, 2006).

Argentina has a stunning agricultural sector that accounts for 55% of the country's exports and 6% of the total GDP (Ministry of Foreign Affairs and Worship, 2014). The agricultural sector is one of the largest contributor of GHG emissions accounting for 35% of the total emissions (World Bank, 2009) of which the livestock domain has the largest share with close to 26% of the total emissions related to manure management and disposal and 82% if enteric fermentation is included (FAOSTAT, 2013). In the livestock domain the cattle industry is one of the most dynamic sectors and ranks 6th in the world with close to 52 million head (FAOSTAT, 2013; SENASA and Ministry of Agriculture, farming and fishing of Argentina, 2015). This research aims to find the biogas potential from cattle manure in Argentina using Buenos Aires Province, the province with the largest cattle inventory, as a case study. The goal of the study is to address two major issues i.e. energy security and the increase in GHG and pollutant emissions associated with the burning of fossil fuels and the poor management of manure. As geographical data and spatial factors play a central role in identifying optimal locations for siting of biogas plants (biomass availability and biogas demand, transportation distances, protected areas, etc) Geographic Information System (GIS), has been used in previous studies. Some studies analyzed the spatial distribution of potential biomass feedstock in order to identify the optimal locations of biogas plants. Höhn et al (2013), for instance, analyzed and identified types and amounts of biomass energy sources in Finland and coupled the findings with suitable biogas plant locations by minimizing transportation distance. Younes et al (2015) analyzed the potential of biogas generation from cattle manure at the province level in Iran and found that up to 3% of the natural gas consumption of the country could be replaced with biogas. Brahma et al (2016) identified the location, types and amounts of biomass energy sources based on minimum transport distance in order to feed an existing biogas plant in rural India. Other studies combined GIS with other tools such as cost-benefit (CB) and multi criteria (MC) analysis to identify the economic potential of biogas production. Delivand et al (2015), for instance, integrated GIS and MC analysis with logistic cost assessment and Life Cycle Assessment (LCA) to identify the optimal locations of power plants in Southern Italy. Sliz-Szkliniarz and Vogt (2011) combined GIS with CB analysis to identify the most suitable locations for crop and manure biogas plant and at the same time evaluate the economic incentive measures necessary to promote biogas development in Poland. There are also a few studies that address the potential of biofuels and biogas in Argentina. Tobares (2012) explained the need to diversify the energy supply of Argentina, a country that has a high dependence on fossil fuels, and introduced the potential of the country for biogas generation thanks to the large-scale agricultural sector. Mathews and Goldstein (2008) emphasized that the strength and success of the soy based biofuels production of Argentina is attributed to the strong regulatory framework to promote biofuels in the country. Hilbert (2011) provided some technical and economic guidelines for biogas production from official sources. However, to the best of our knowledge, no study has optimized the spatial diffusion of biogas plants by integrating geographical land suitability analysis combined with scenario modeling based on cluster analysis. This study carries out a detailed geospatial analysis and introduces a rigorous selection method that allows us to identify the potential optimal sites for biogas plants in Buenos Aires Province, based on GIS land suitability analysis. The study then proposes three scenarios based on cattle farm size and by minimizing the distance to urban areas as well as within groups of farms with the use of spatial statistical analysis. The use of statistical methods is a novel application of GIS that helps us find the statistically significant spatial clusters and determine the optimal location, number and scale of biogas plants under the proposed scenarios. Cluster analysis helped us identify the groups of farms with similar characteristics by minimizing the distance among them. This is very important, especially in countries or regions with a large number of cattle farms and size. The rest of the paper is arranged as follows: chapter 2 introduces the scope of the study and the proposed methodology with a detailed explanation of the GIS tools and scenario design, chapter 3 estimates the power generation capacity of the proposed scenarios taking into account technical parameters, and finally chapter 4 concludes and integrates the research outcomes with existing policy frame in the country.

2. Scope of the study and proposed methodology

Even though Argentina is not one of the top polluters in terms of GHG emissions, the country has the second highest methane (CH_4) emissions in South America (World Bank Statistics, 2016b). In 2010, the total CH_4 emissions reached 86734 thousand metric tons of CO_2 eq. accounting for 46% of the total emissions of GHG (World Bank Statistics, 2016b and 2016c). The agricultural sector alone contributes about 73% of the total CH_4 emissions in Argentina. Due to a rapid and continuous increase in global grain demand, the agricultural sector in Argentina has allocated more land to grain production (Viglizzo et al, 2011). This has had an impact on cattle production activities changing from extensive farming to intensive. The shift to intensive cattle production has exacerbated the environmental problems, as effluents are usually discharged directly into soil or stored in lagoons affecting the quality of water, soil, air and public health (FAUBA, 2016)

On the other hand, most of the electricity produced and consumed in the country comes from fossil fuels. Around 60% of the power produced in Argentina is generated from the flaring of natural gas and other fossil fuels (CAMESSA, 2014). This situation poses a serious threat to the energy security and socio-economic development of the country. Moreover, Argentina will probably continue growing in the coming years pushing the energy demand and dependence on imported gas even further (BMI Research, 2016).

In this research we argue that the implementation of biogas technology that uses cattle manure as substrate will not only provide environmental and socio-economic benefits, but will also promote sustainable agriculture with the use of renewable energy and increase energy independence contributing to the diversification of Argentina's energy supply.

2.1 Case study: Buenos Aires Province

Argentina has 23 provinces where Buenos Aires province, with a geographic area of 307571 Km^2, is the largest in the country covering 11% of the total territory. It has a population of more than 15 million people accounting for 38.9% of the country's population. Buenos Aires province alone contributes 31.7% of the total GDP. The country's capital, Autonomous City of Buenos Aires, is also located in this area and produces 20.5% of the total GDP. In total around 50% of the GDP of the country is produced in this area. The main economic activities rely on the following sectors: automotive, industry, grain, oilseed, cattle, oil, steel and tourism (Ministry of Treasury and Public Finances, 2015). The productivity of this province, mainly due to the richness of its lands and diversity of industries, has encouraged internal migration since the 1950's (Ministry of Economy of Buenos Aires Province, 2014). The extensive migration coupled with rapid economic growth in the province has caused a significant increase in power demand, reaching 50% of the total country's demand (CAMESSA, 2014). Argentina is an important oil and natural gas producer and has also one of the largest endowments of shale gas, which seems to be very promising in the future. However, the decline in its fossil fuel production and rapid increase in energy demand turned the country into a net importer in 2008 (U.S EAI, 2012). Since last decade, the country has faced power shortages during winter season affecting the industrial sector's productivity as well as residences. There was also a change in the types of energy sources used for power generation. As shown in Figure 1 there has been a steady rise of electricity generation via thermal power, whereas there has been a persistent relative decrease on electricity generation by hydropower and nuclear energy (CAMESSA, 2014).

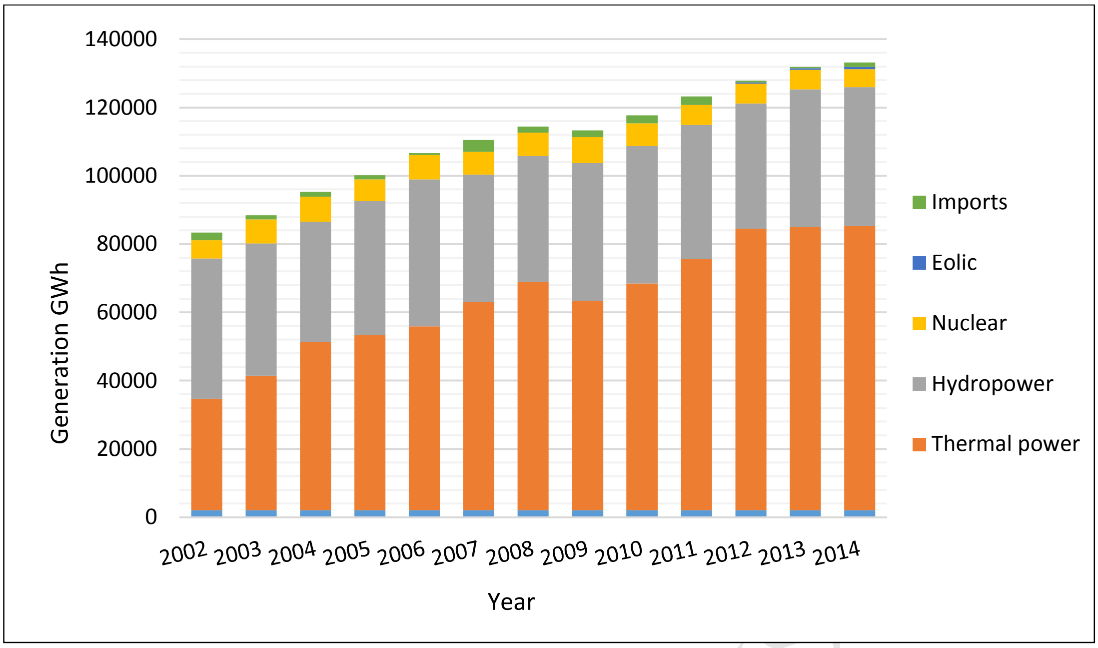

Figure 1. Generation of electricity according to primary energy source in Argentina

From the agricultural sector, the livestock domain is extremely important in Argentina. For bovines for example, it ranks 6th in the world with close to 52 million head (SENASA and Ministry of Agriculture, farming and fishing of Argentina, 2015). In Buenos Aires province, the cattle inventory for 2016 accounts for 35% of the total with more than 18 million head distributed in 60885 farms (SENASA, 2016) (see Figure 2).

At the same time, crop production has been one of the major drivers of Argentinian economy. The highest production comes from soybean, corn, wheat and barley (Ministry of agroindustry of Argentina, 2016). Between 2001 and 2015, for example, soybean production experienced a four-fold increase (SIIA, 2015). This increase in production accelerated the transition to industrial farming and production activities have changed from extensive to intensive farming. Besides the unsanitary conditions for the animals, the shift to intensive cattle production has also exacerbated the environmental problems as effluents are usually discharged directly into soil or concentrated in lagoons affecting the quality of water, soil, air and public health (FAUBA, 2016). As shown in figure 3 around 73% of the manure goes to anaerobic lagoons (both natural or artificial) and the rest is spread on the fields, or directly spilled into the streams (Hilbert, et al. 2006). The poor management of manure impacts directly on the ground, alters their properties and, therefore, affects the quality of water bodies and also contaminates groundwater that supplies human activities.

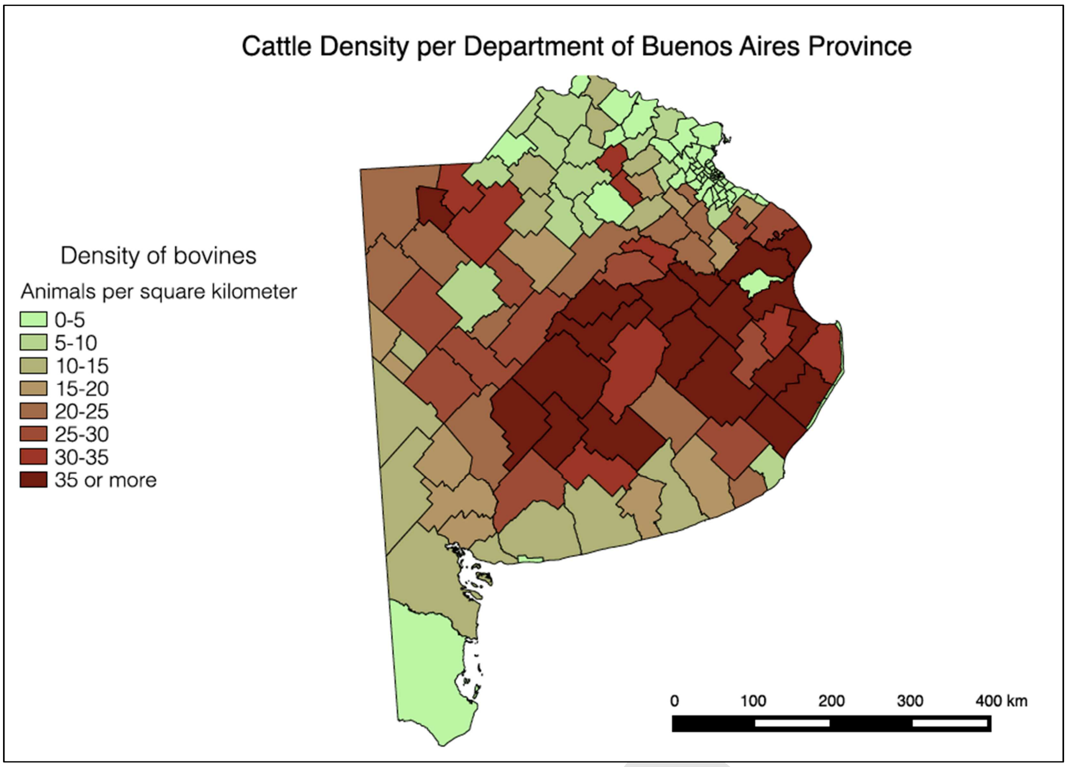

Figure 2. Cattle density per department of Buenos Aires Province

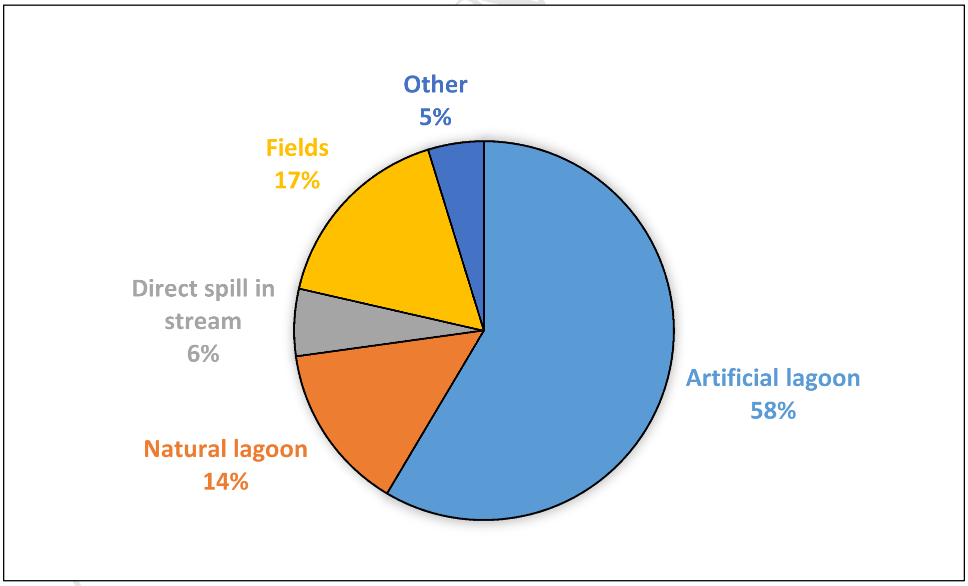

Figure 3. Final disposal of manure in bovine farms in Argentina

2.2 Methodology framework

This study first identified the potential areas for the siting of biogas plants by analyzing geographical, environmental and socio-economic criteria. After identifying theoretical suitable areas, the study proposed three scenarios based on the farm scales (small, mid and large size) and by minimizing the distance to urban and rural areas as well as within clusters of farms. In this stage the study introduced on site large-scale biogas plants and centralized biogas plants depending on the size of the farms and manure availability. The details of the methodology framework are summarized in figure 4.

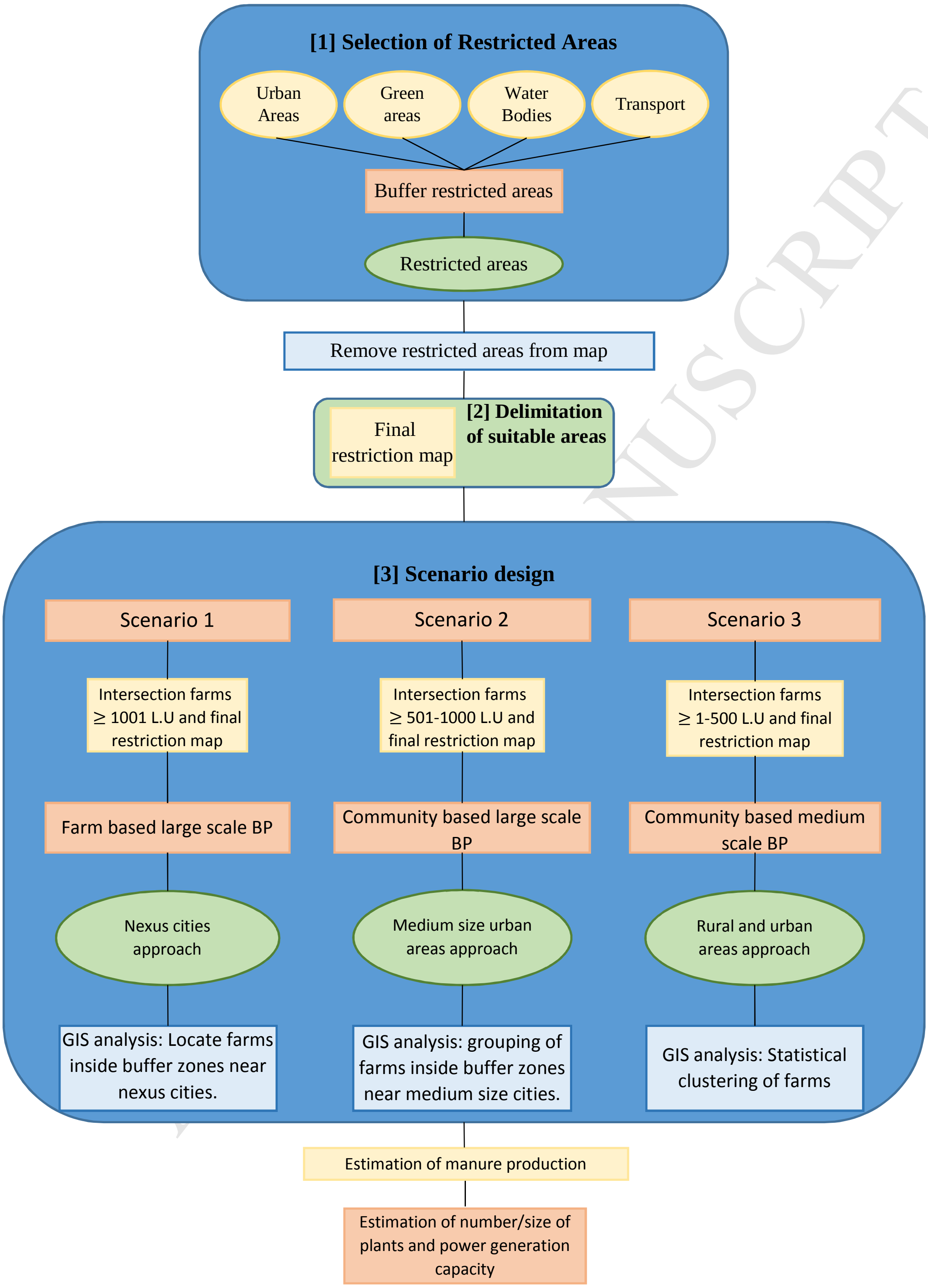

Figure 4. Research methodology framework

2.2.2 Selection of suitable areas: GIS restriction analysis

The definition and identification of the restricted areas for the development of potential biogas plants was achieved through the use of ArcGIS 10.2 and based on geographical, environmental and socio-economic criteria. The identification of restricted areas is given by a modified version of Ma, et al., 2005 in **eq. 1**

$$R=\prod_{i=1}^{n} \tau\, i \qquad \text{eq. (1)}$$

Where,

R = Restricted areas

τi = Criteria for restrictions

Table 1 shows the criteria used to identify the restricted areas that could be sensitive to the development of biogas plants. Buffer zones were applied to the restricted areas in order to avoid close proximity to such places: urban areas and transport stations (Ma, et al., 2005), water bodies (Thompson, et al., 2013) and green, protected and inadequate areas (Silva, et al., 2014). A buffer is a zone around a map feature measured in units of distance. Biogas plant sites should be located as far away as possible from biophysical elements such as water, and other areas with ecological and agricultural value in order to reduce the risk of contamination and to protect the environment. The use, occupancy and type of the soil should also be considered to minimize the impacts on their use and to reduce risks. That is the reason, buffer zones were applied to the restricted areas to define an exclusion zone.

Specific criteria	Buffer zones	References
Urban areas	Outside 1km buffer	Ma, et al., 2005
Water bodies	Outside 200m buffer	Thompson, et al.,2013
Transport stations	Outside 500m buffer	Ma, et al.,2005
Green, protected and inadequate areas	Outside 200m buffer	Silva, et al.,2014

Table 1. Criteria for identifying restricted areas for the siting of biogas plants in Buenos Aires

The study created a model using the ModelBuilder function of ArcGIS and taking into account the restrictions proposed in Table 1. The ModelBuilder function is a visual programming language for building geoprocessing workflows (ESRI, 2016). In a ModelBuilder model, each case is represented as a diagram that chains together sequences of processes and geoprocessing tools, using the output of one process as the input to another process. The model proposed here has four restrictions represented as geographical vector features with different shapes (points, lines and polygons). In the first step, each restriction was identified taking into consideration the location and shape of the features, which are represented in layers (basically a layer is the visual representation of a geographic dataset in any digital map environment). After that we applied buffer zones to the restrictions. In the next step and in order to homogenize the vector features the model converted them into raster data. In this step the model performed a conditional function to differentiate the restricted areas from the suitable areas. Finally, all restrictions were combined in order to obtain the final suitability map. The designed Modelbuilder is shown in appendix 1. Figure 5 shows the map highlighting the excluded and suitable areas in Buenos Aires Province.

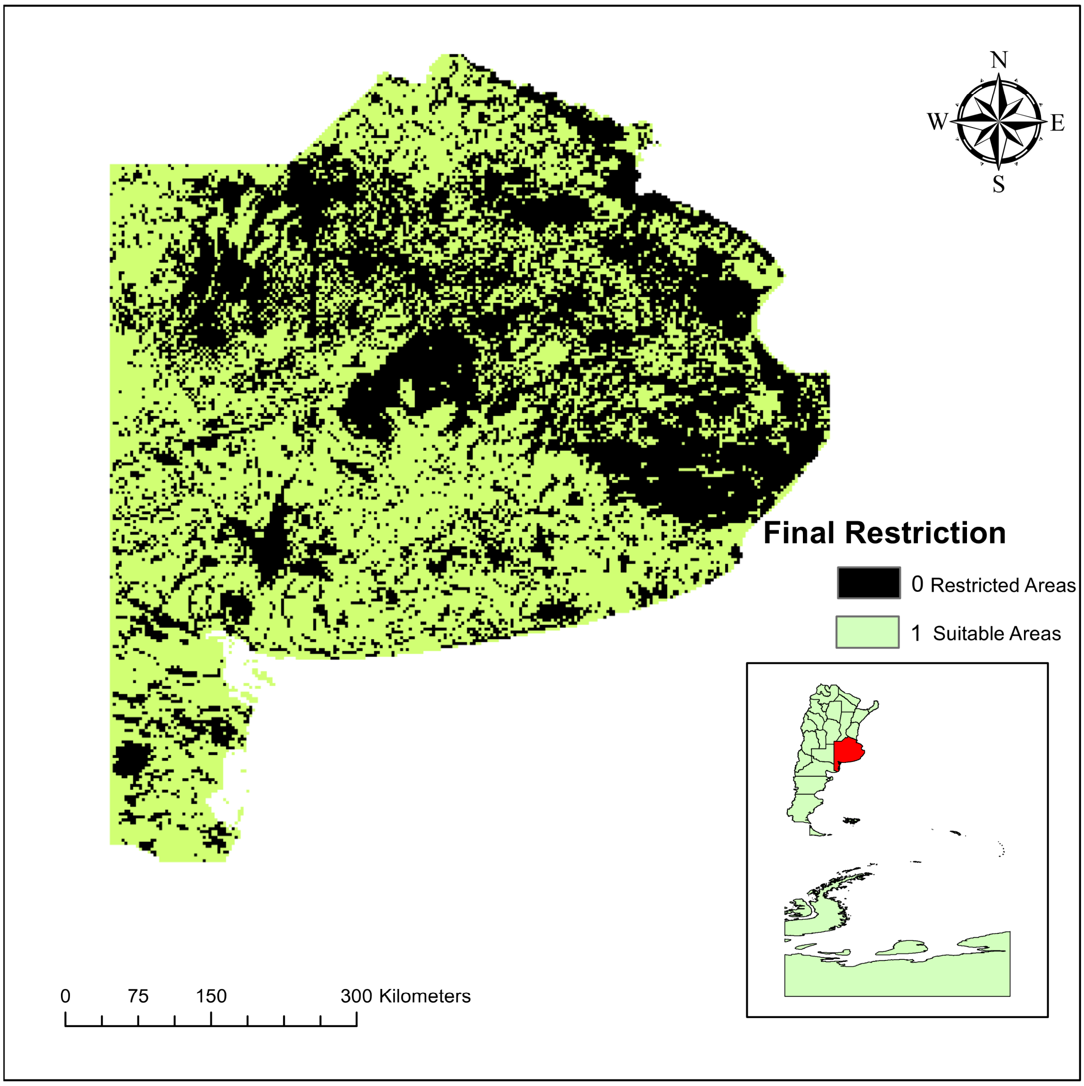

Figure 5. Restricted and suitable areas in Buenos Aires Province

2.3 Scenario design

As mentioned in section 2.1 Buenos Aires Province has the largest cattle inventory in the country. Since the purpose of this research is to identify the most suitable locations for the installation of biogas plants using a very rigorous selection process, the study proposed three scenarios based on the size of the cattle farms in the province (SENASA, 2016): small size (1-500 head), mid-size (501-1000) and large size (1001-more). In each scenario specific parameters and conditions were introduced to obtain the optimum number of biogas plants. (Appendix 2 provides a table with all the cattle farm inventory of Buenos Ares Province). When considering economic feasibility of a candidate site, the proximity to the electricity network, cities, roads, and soil types are important. At the same time, biogas technology is considered to have a significant impact on the population living within close proximity to the site, due to concerns such as aesthetics, odor, safety, noise, decrease in property value and health hazards (Luostarinen, 2013). The 20 km buffer region minimizes the transportation costs of the manure for the cases where community based biogas plants (CBBP) were introduced; ensure proximity to electricity grid and to allow the potential use of heat in neighboring areas (IEA, 2014).

2.3.1 Scenario 1: large size farms

Scenario 1 identifies the best locations for large-size farms. As these farms have more than 1000 head the scenario assumes the biogas plants will be located on site. Currently in Buenos Aires there are 3,519 large-size farms reaching a total 6,810,442 head (SENASA, 2016). In order to minimize distance to power networks and urban areas, and based on previous studies, the farms with potential for biogas production must be in a radio of 20 km of cities that are located in the suitable areas previously identified (IEA, 2014). In this scenario we propose to consider "hub cities" or metropolitan areas that play a role as hubs between large urban areas and smaller cities or rural areas. The reason hub cities were selected for this scenario is because they are urban centers relatively better connected with the rest of the territory than the urban centers of lower rank, and in some regions, these cities are the only link between metropolitan areas and rural areas. This is verified from different perspectives from the access to infrastructure networks such as roads, airports or railways, or the characteristics of its digital infrastructure -access to a higher bandwidth internet or presence of computer services - and also with the characteristics of institutional and business context itself (Michelini and Davies, 2009). Hub cities have more resources, investment opportunities and infrastructure available for this kind of projects. Over the past two decades in Argentina, hub cities have shown a greater demographic dynamism than other urban centers of higher and lower hierarchy and it is expected that these trends will continue. There are various definitions of hub cities and most of them are based on population size (Bellet, 2000). In this research we stress that the role of a hub city must be given not only by the number of inhabitants, but also by the degree of demographic growth towards the development of local industries and services (Sassone, 2000). This study employs the results of Manzano and Velazquez (2015) that identified 16 cities in the Buenos Aires Province considering population, infrastructure, political administration and future potential growth (see Table 2)

Hub Cities	Population (2010)
Gran La Plata	787,000
Mar Del Plata	593,000
Bahia Blanca	291,000
San Nicolas De Los Arroyos	134,000
Tandíl	117,000
Zárate	99,000
Luján	97,000
Pergamino	91,000

Olavarria	90,000
Junín	87,000
Campana	87,000
Necochea	85,000
Punta Alta	58,000
Chivilcoy	58,000
Mercedes	56,000
Azul	56,000

Table 2. Hub cities in Buenos Aires Province

In the first step of the analysis, an intersection of the suitable areas (which was converted into polygon feature) with the location of the farms was made as shown in figure 6.

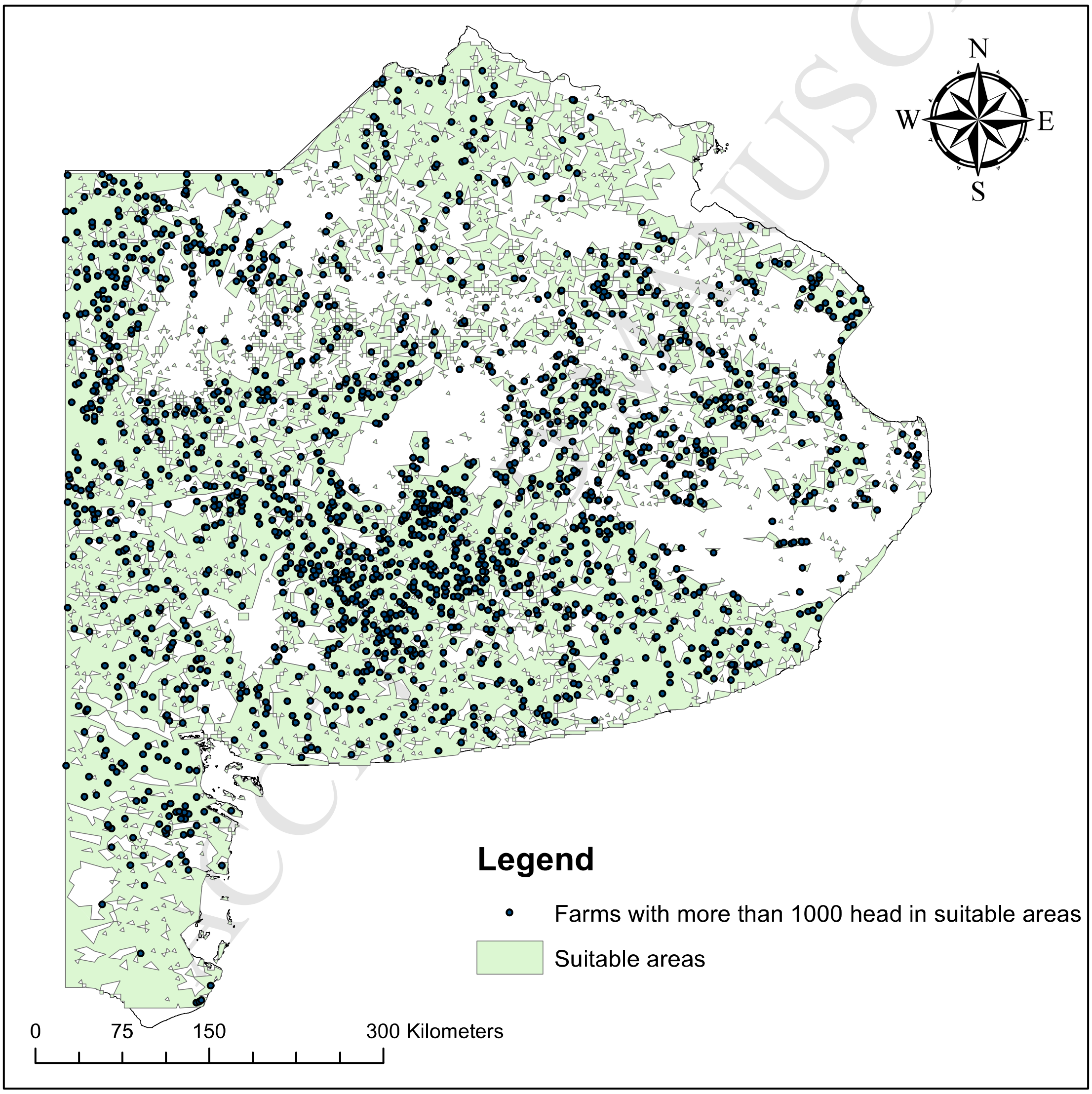

Figure 6. Large scale farms within suitable areas in Buenos Aires Province

The study then applied a buffer area of 20 Km for the hub cities of the province and identified the farms within the buffer areas (Figure 7)

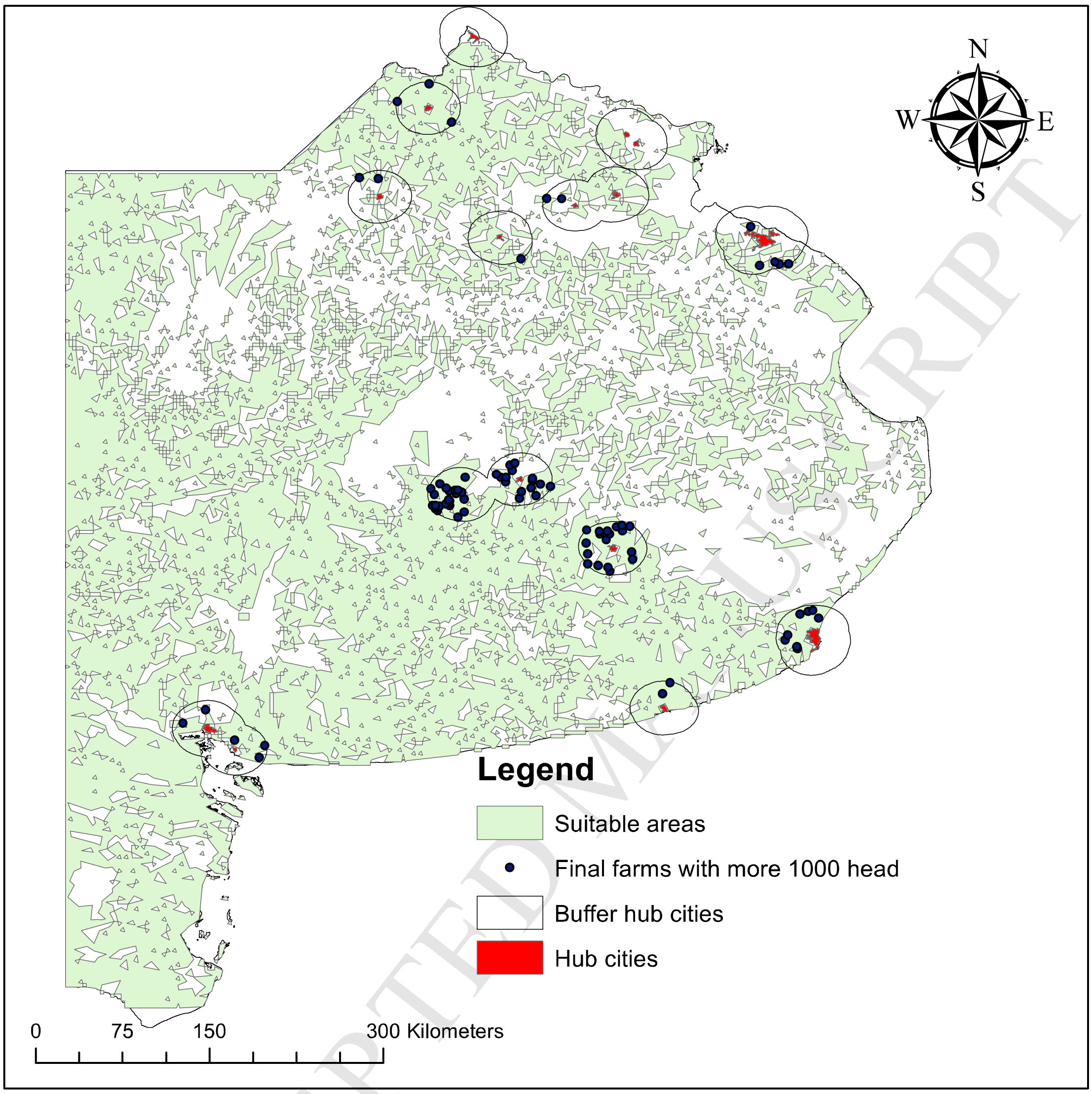

Figure 7. Final selection of large size farms in Buenos Aires Province

By applying these conditions for scenario 1 it was possible to reduce the number of potential farms from 3519 to 90 and the number of cattle head from 6810442 to 177408. This screening process is very important since it allows the identification of the farms with the highest potential for the installation of biogas plants.

2.3.2 Scenario 2: mid-size farms

Scenario 2 identifies the optimal biogas plants location for mid-size farms. The difference with scenario 1 is that, in this case the goal is to design CBBP that will operate with the manure of the grouping of farms located within the buffer zones of mid-size cities. This is a very popular practice in Europe as it helps communities and farms to be self-sufficient in terms of heating and in many cases electricity supply (Al Seadi, 2000).

Currently Buenos Aires province has 5665 farms of this size, reaching a number of 3939388 head (SENASA, 2016). This scenario identifies the best location for biogas plants inside the suitable areas and in a radio of 20 km of those cities with more than 20000 inhabitants (see Table 3). This selection was based on mid-sized cities considering population only (Ministry of Economy of Buenos Aires Province, 2014). These plants will eventually contribute to the regional development and help meet future electricity demand of those cities. Similar to scenario 1, in the first step of the analysis an intersection of the suitable areas with the location of the farms was made as shown in Figure 8.

Cities with more than 20,000 inhabitants in Buenos Aires Province	Population	Cities with more than 20,000 inhabitants in Buenos Aires Province	Population
Coronel Pringles	20,263	Balcarce	44,064
Carmen De Patagones	20,533	Tres Arroyos	47,174
Granaderos	20,548	San Pedro	47,452
San Vicente	21,411	9 De Julio	47,733
Manuel B Gonnet	22,963	Marcos Paz	50,460
Carlos Casares	23,000	Belen De Escobar	54,678
San Antonio De Areco	23,138	Azul	56,000
Colon	23,206	Mercedes	56,000
Villa Gesell	23,257	Punta Alta	58,000
Coronel Suarez	23,612	Chivilcoy	58,000
Las Flores	23,871	Base Naval Puerto Belgrano	58,315
San Carlos De Bolivar	26,242	Canuelas	59,364
Arrecifes	26,400	Necochea	85,000
Dolores	27,042	Campana	87,000
Lincoln	28,051	Junin	87,000
Baradero	28,537	General Rodriguez	87,491
Lobos	29,863	Olavarria	90,000
Miramar	30,100	Pergamino	91,000
Pehuajo	31,533	Lujan	97,000
Salto	32,653	Zarate	99,000
Bragado	33,222	Tandil	117,000
Trenque Lauquen	33,442	San Nicolas De Los Arroyos	134,000
Chascomus	33,607	Bahia Blanca	291,000
25 De Mayo	36,842	Mar Del Plata	593,000
Saladillo	37,000	Gran La Plata	787,000
Chacabuco	38,418	Ciudad Autonoma De Buenos Aires	2,890,151
Pinamar	39,371	Gran Buenos Aires	12,806,866

Table 3. Mid-size cities in Buenos Aires Province

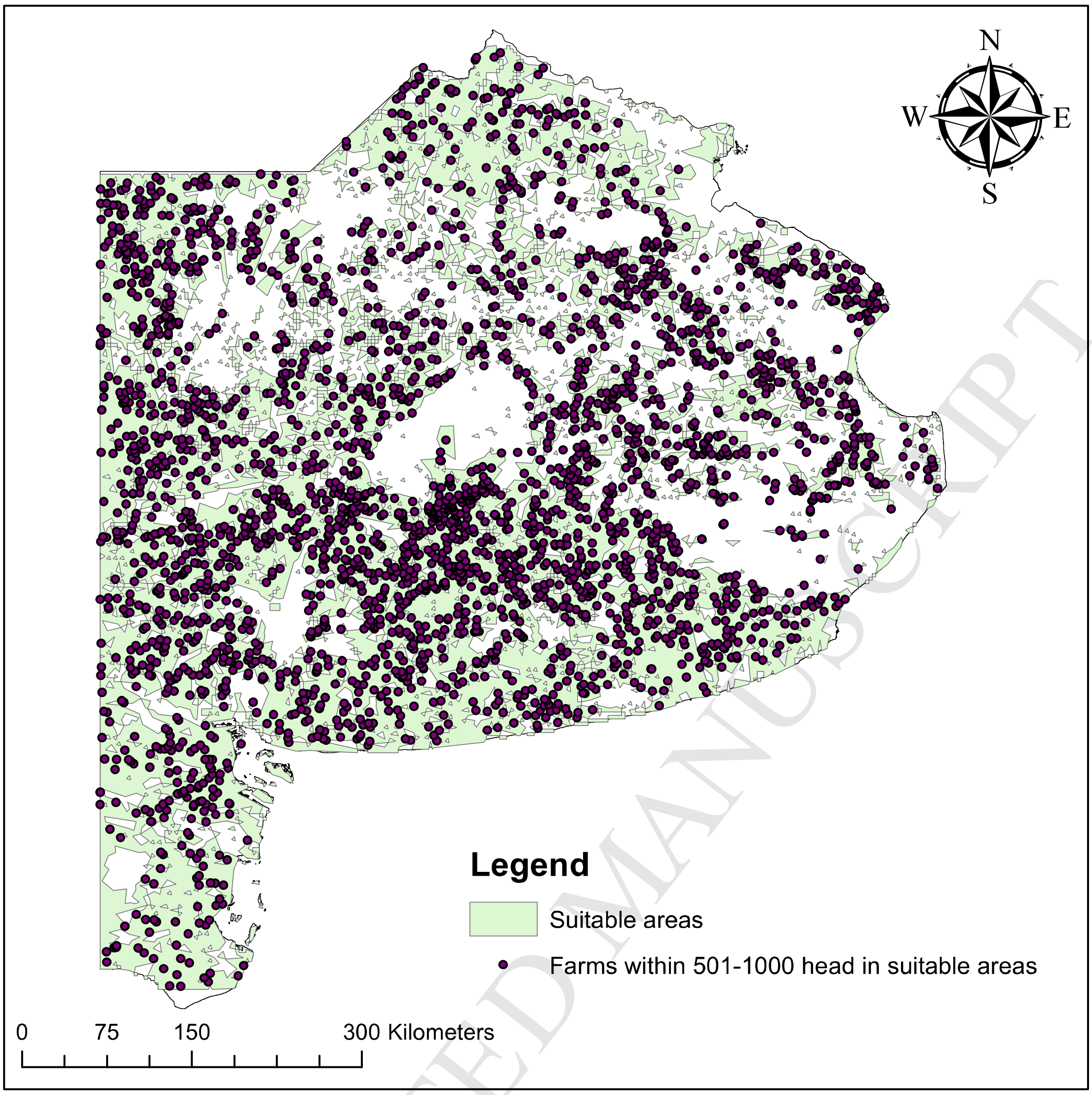

Figure 8. Mid-size farms within suitable areas in Buenos Aires Province

After that a buffer of 20 Km from mid cities was applied (Figure 9) and identified the farms within the buffer areas. Thanks to this it was possible to reduce the total number of farms from 5665 to 506 and the total number of head to 343811.

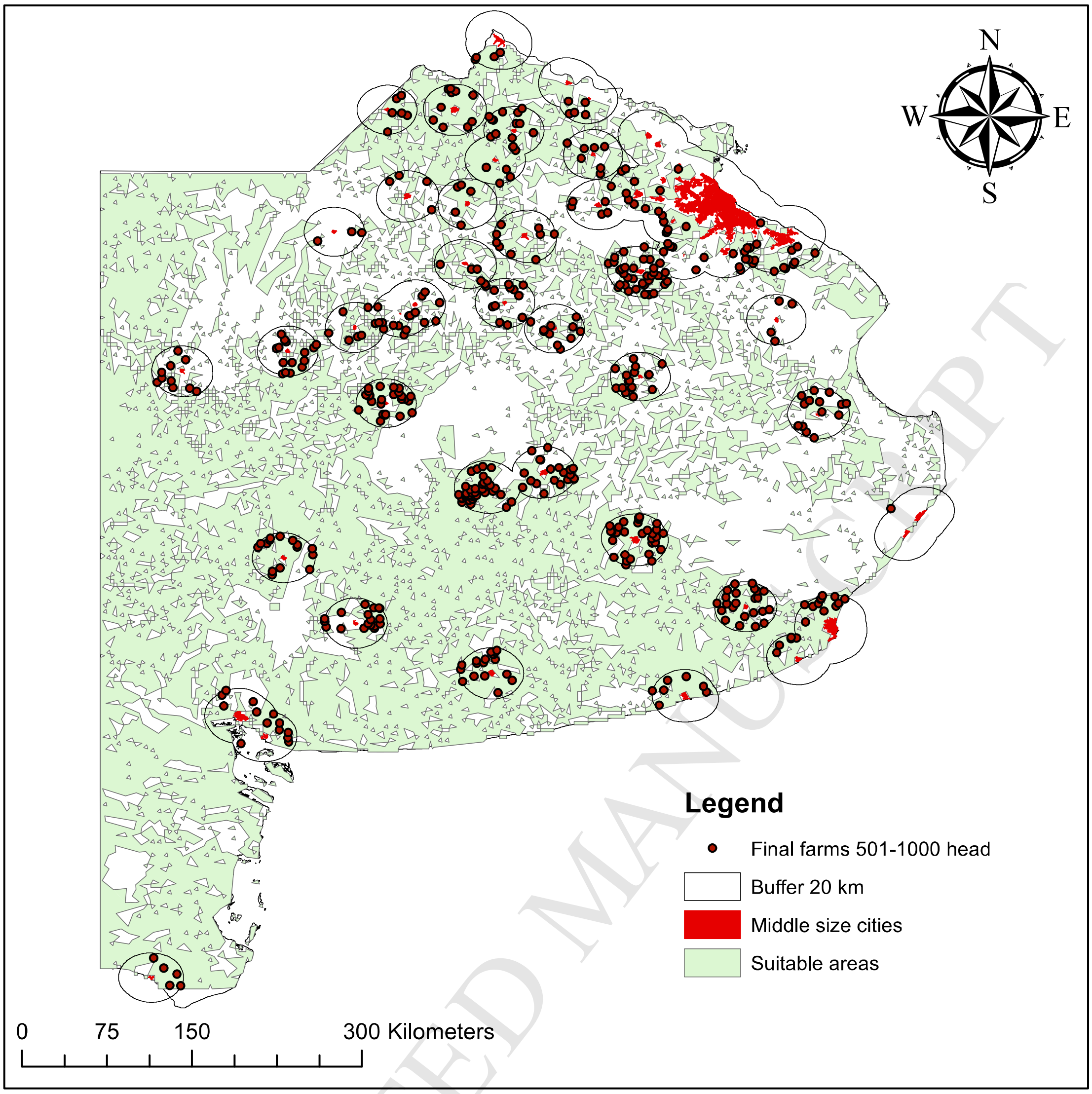

Figure 9. Final selection of mid-size farms in Buenos Aires Province

2.3.3 Scenario 3: small size farms

Scenario 3 aims to find out the best location for CBBP. Currently Buenos Aires Province has 51701 small farms reaching a total 7307523 head and accounting for 40.5% of the total cattle inventory (SENASA, 2016). In Argentina those farms that range from 1 to 100 head are considered as very small scale (Ministry of Agriculture, Farming and Fishing of Argentina, 2014). Farms with less than 100 head face some difficulties to contribute to CBBP mainly because the burden of transportation costs of the manure is high as such farms are usually family-owned and not necessarily intensive yet. For this reason, the study did a further selection of farms with more than 100 head. Similar to the other two scenarios in the first step of the analysis, an intersection of the suitable areas with the location of the farms was done as shown in Figure 10.

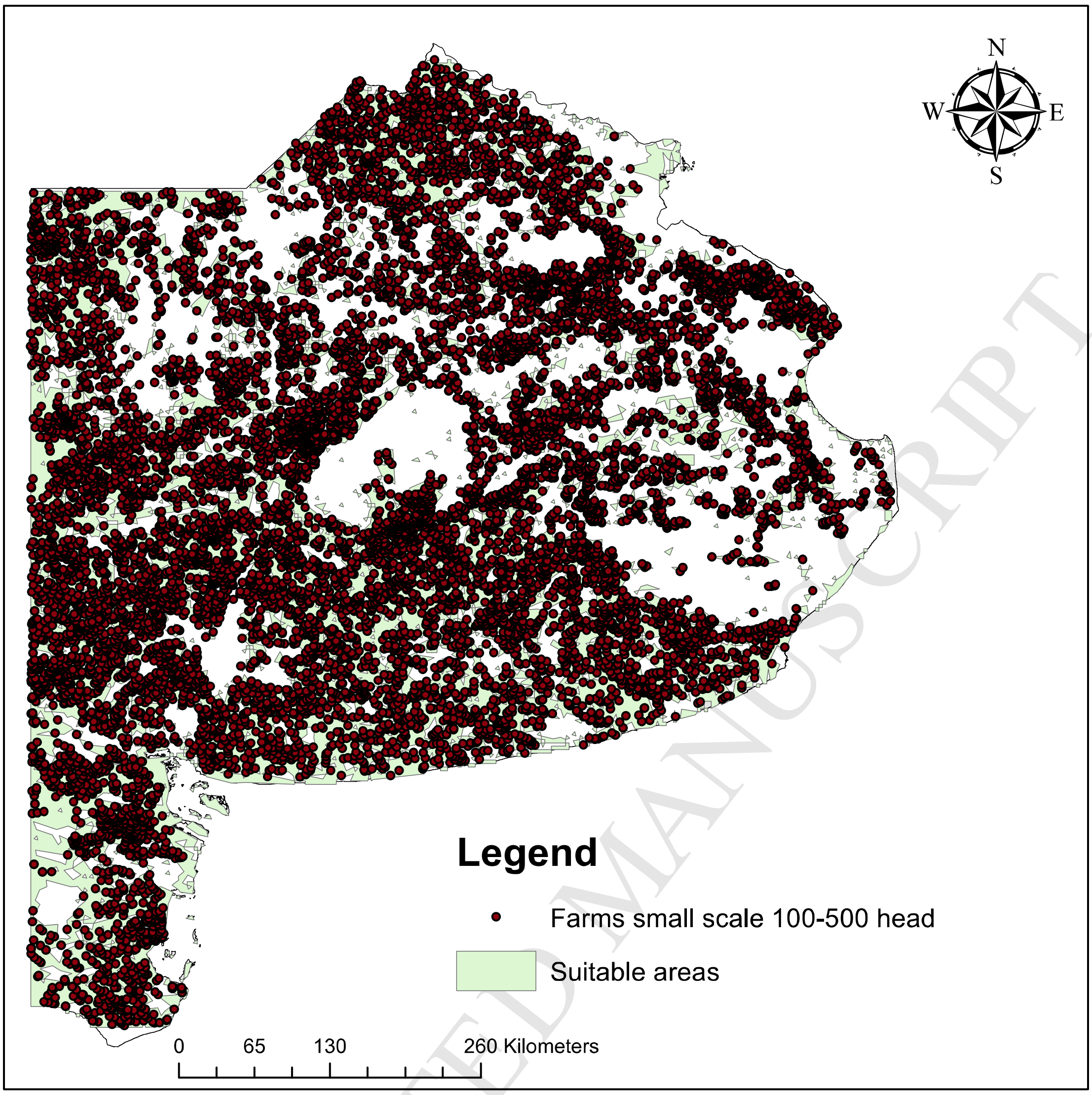

Figure 10. Small size farms within suitable areas in Buenos Aires Province

After this restriction the number of farms was reduced to 14000, a number still high to perform the same type of analysis as the previous scenario. Accordingly, the study applied a cluster analysis from the spatial statistics tool of ArcGIS to identify the optimal locations for CBBP in the province. Spatial autocorrelation in GIS helps us understand the degree to which one object is similar to other nearby objects. The first step was to find out whether there was any clustering or spatial correlation among the small farms by applying Spatial Autocorrelation (Morans I). Moran's I (Index) is used to measure spatial autocorrelation. Positive spatial autocorrelation happens when similar values cluster together in a map and negative spatial autocorrelation when dissimilar values cluster together in a map. In conclusion if Moran's I index is positive, spatial correlation exists. This means that the higher the z-score the more intense is the clustering**.** As shown in figure 11, the z-score of

11.87 confirms that there is less than 1% likelihood that this clustered pattern could be the result of random choice.

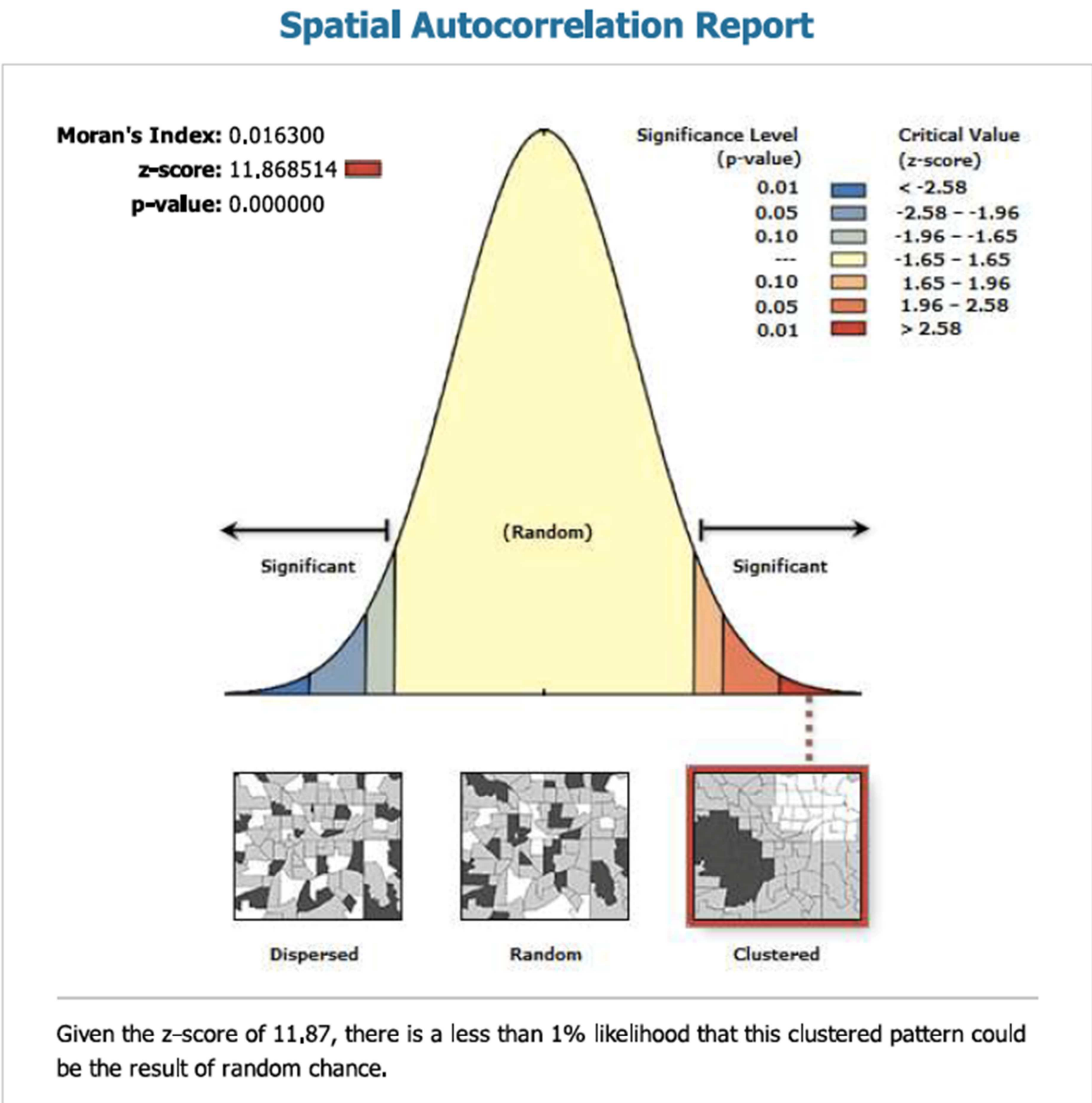

Figure 11. Spatial autocorrelation report of small size farms in Buenos Aires Province

The next step was to identify at what distance the clustering for the farms was maximized. To achieve this objective the study first applied the utility function "Calculate the Distance Band from Neighbor Count" to identify the distance at which any given farm had at least one neighbor. This function was used to identify at what scale of distance the clusters are maximized, it is useful because the way the clustering occurs can vary, so it is important to know what scale is more prominent.

The results of the test of distance band from neighbor gave an average distance of 1.5 km and a maximum distance of 19 km. The study then applied the Incremental Spatial Autocorrelation to find out the peak where the clustering was maximized, this function measures spatial autocorrelation for a series of distances and creates a line graph of those distances and their corresponding z-scores. As z-scores reflect the intensity of spatial clustering, statistically significant peak z-scores indicate distances where spatial processes promoting clustering are most pronounced. As shown in Figure 12 the peak was reached at 7.5 km.

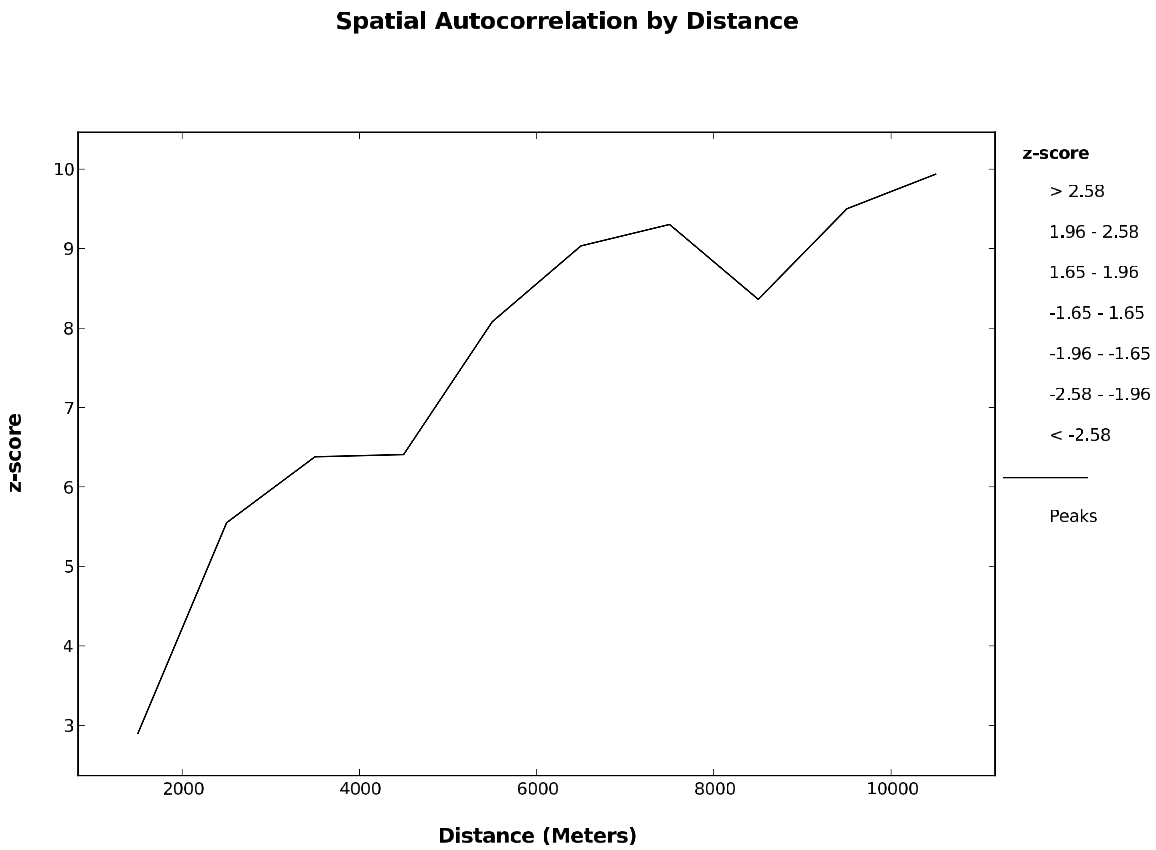

Figure 12. Incremental spatial autocorrelation for small size farms in Buenos Aires Province

After that Hot Spot Analysis (GETIS-ORD GI*) was applied and found that 701 farms experience strong spatial correlation (see Fig. 13). A Hot Spot Analysis is used to find out those features with the strongest autocorrelation. GETIS-ORD GI* in GIS evaluate each feature within the context of neighboring features (ESRI, 2016). To be a statistically significant hot spot, a feature needs to be surrounded by other features.

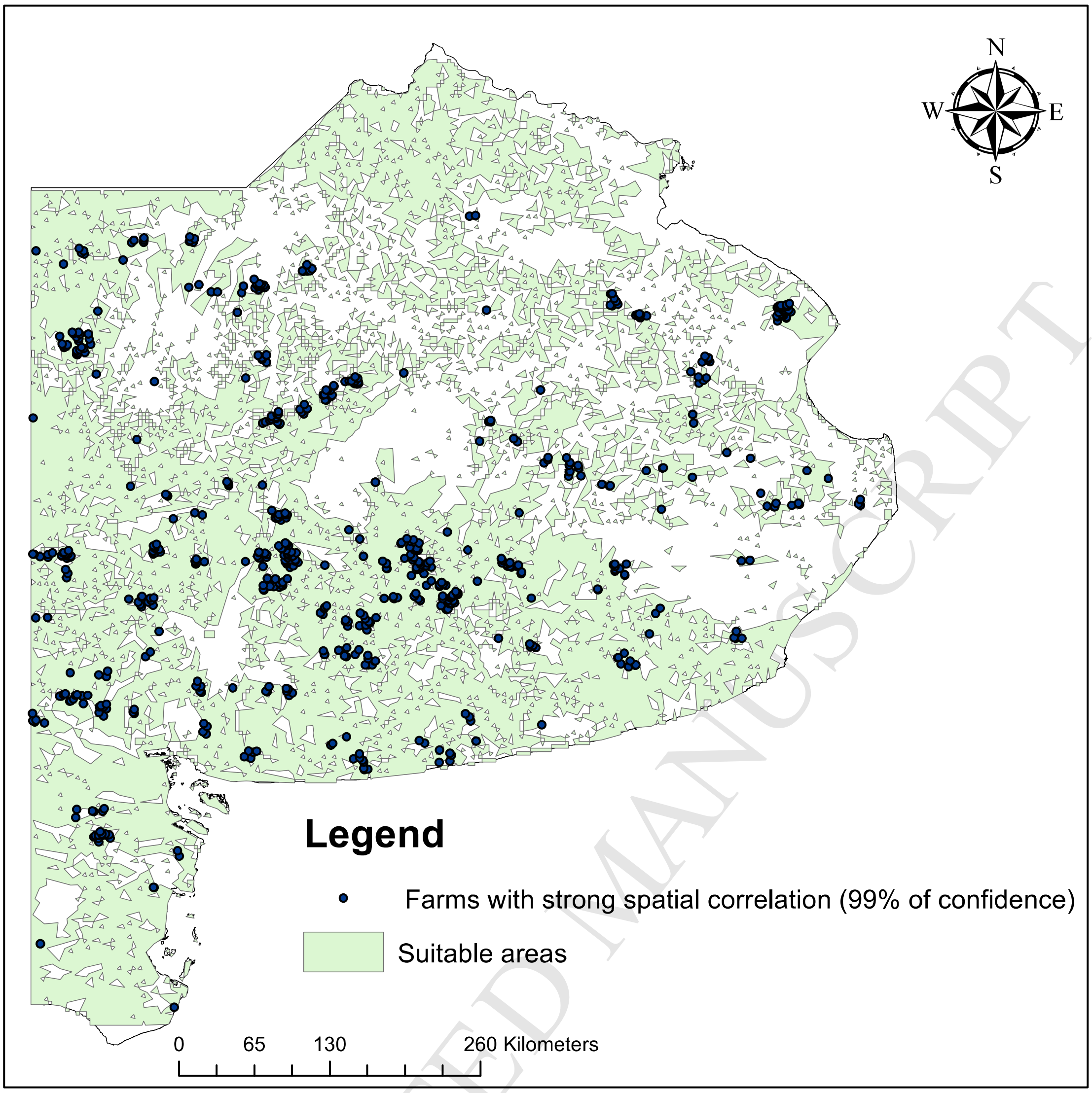

Figure 13. Hot Spot Analysis (GETIS-ORD GI*) of case study

Due to the strong autocorrelation of farms and proximity to each other, no small scale CBBP were considered. To identify the best locations for medium and in some cases large scale CBBP the study applied a buffer of 20 km around all the places of Buenos Aires were human activities are conducted including cities and rural areas. These plants could contribute to the local development and help meet the energy demand of those communities (Figure.14)

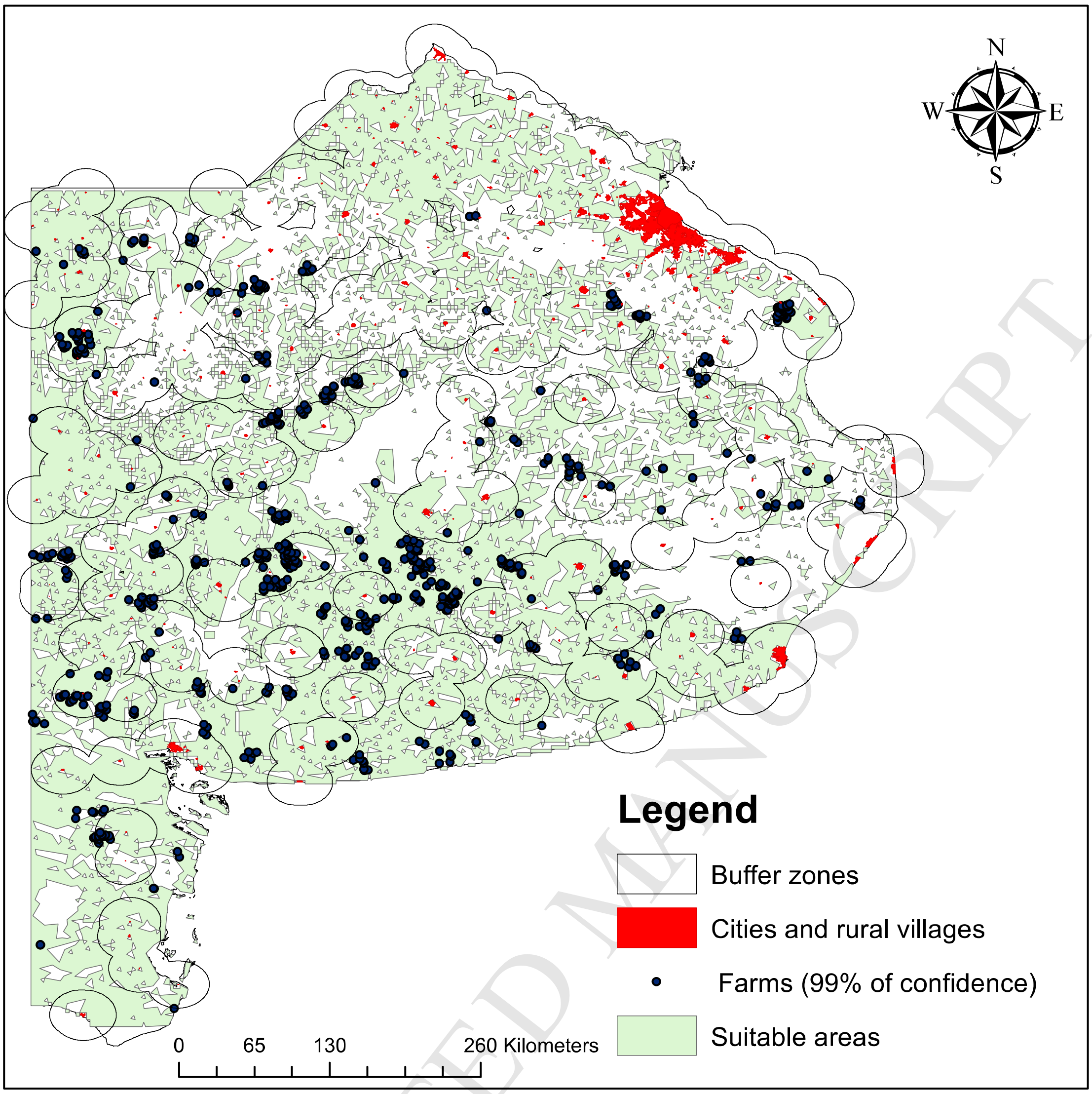

Figure 14. Final selection of small size farms in Buenos Aires Province

Finally, the intersection of the buffer zones with the selected farms identified 343 farms with a total 109219 head available for biogas production (Figure. 15).

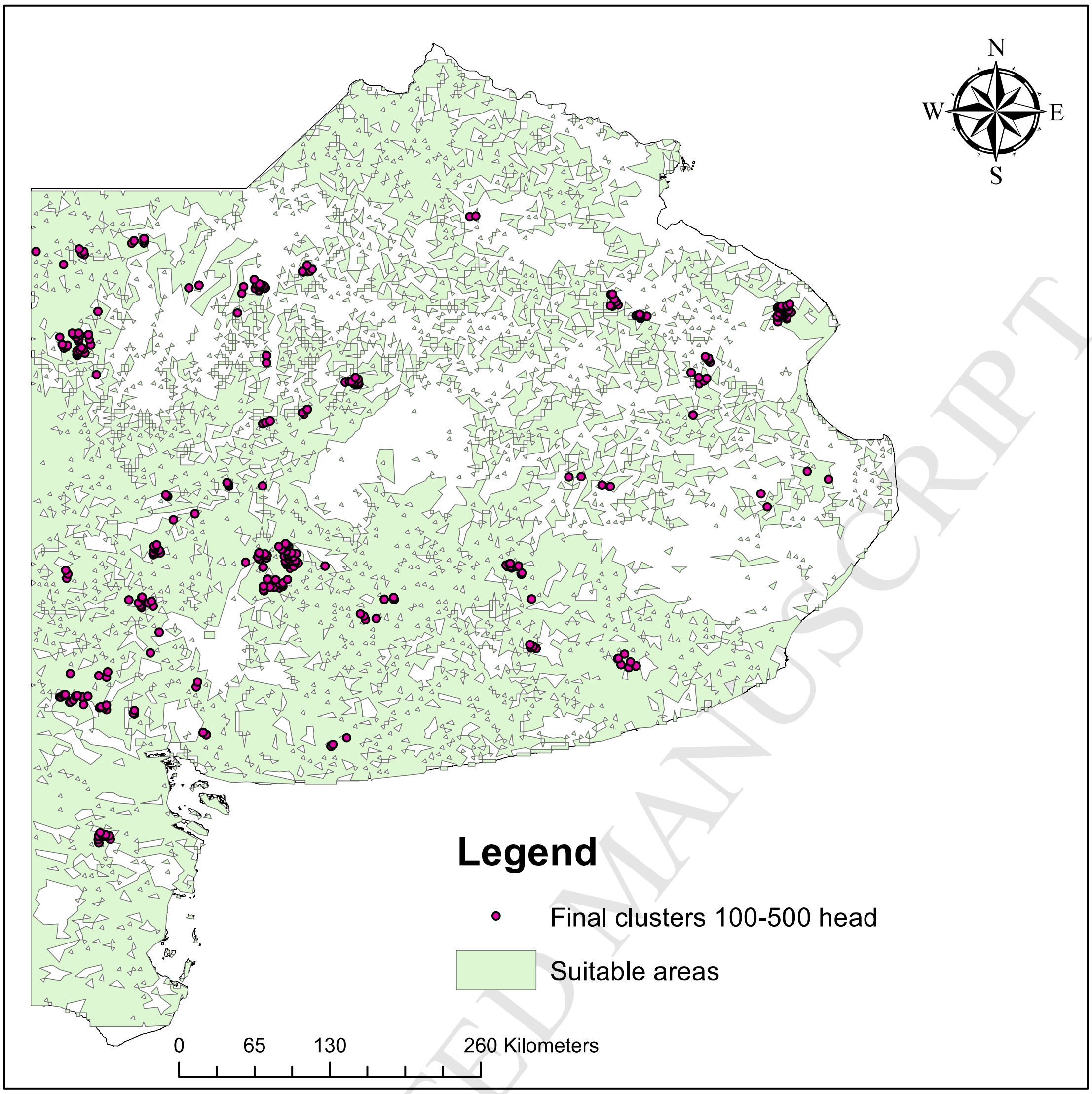

Figure 15. Final clustering of small scale farms in Buenos Aires Province

3. Results and discussion

The goal of the study is not only to identify the best location for the installation of biogas plants at different farm sizes, but also to estimate their potential power generation capacity. The results show to what extent the electricity demand of Buenos Aires Province can be met with the use of this renewable source of energy. During the year 2014, power demand in Buenos Aires province (including the Autonomous City of Buenos Aires) reached a total of 63510 GWh representing half of the total consumption of Argentina.

The size of the plants are based on the energy potential production that depends on the amount of manure available to be used as substrate.Three types of plants that generate combined heat and power (CHP) were proposed (Madlener et al 2010). This research avoided to work with those farms, or CBBP with a capaciy under 250 KW_{el} , experience from Germany shows that, biogas plants, with sizes below 250 kWel need special efforts to be economically viable, (Al Seadi, et al., 2000).

1. With a capacity ≥250 KW_{el} →Substrate demand for 250 KW_{el} of 5455 T/y
2. With a capacity ≥500 KW_{el}→Substrate demand for 500 KW_{el} of 10909 T/y
3. With a capacity ≥1000 KW_{el}→Substrate demand for 1 MW_{el} of 21818 T/y

After identifying the size of the plants, the study conducted a very detailed estimation of the manure availability, by not only taking into consideration the average manure production of a regular cow, but also considering its type and average weight. The analysis also included the manure collection efficiency in intensive cattle farming (USDA, 1995). The results of the analysis helped us estimate the potential power generation capacity of the three types of plants (see appendix 3, 4 and 5). Table 4 shows the details of the results for each scenario.

Scenario 1	Scenario 2	Scenario 3
• 90 onsite potential plants • Collection rate = 90% • Total potential substrate of this scenario= 1,454,008.3 T/y **Size of potential Biogas plants** • ≥ 250KW= 29 • ≥ 500KW=44 • ≥ 1MW=17 • Power generation capacity of all the farms = 65.795MW_{el}.	• 46 community based biogas plants • Collection rate = 90% • Total potential substrate of this scenario= 2,889,186.093T/y **Size of potential Biogas plants** • ≥ 250KW=4 • ≥ 500KW=3 • ≥ 1MW=39 • Power generation capacity of all the farms = 132.33 MW_{el}	• 39 community based biogas plants • Collection rate = 90% • Total potential substrate of this scenario= 934,622.4178T/y **Size of potential Biogas plants** • ≥ 250KW=6 (- 6 less than 250KW) • ≥ 500KW=14 • ≥ 1MW=13 • Power generation capacity of all the farms =42.657MW_{el}

Table 4. Size of potential biogas plants and power generation capacity

The study then estimated the net heat and power generation capacity of the proposed scenarios assuming the biogas plants generate CHP (also known as cogeneration or biogas CHP plants). Table 5 shows a detailed description of the technical parameters of the three types of biogas plants including electricity and heat production, energy conversion efficiency and substrate demand (Ministry of Food Agriculture and Consumer Protection of Germany, 2012). Table 5 also shows the technical description of the 3 scenarios in order to find out the potential contribution to the energy demand in Buenos Aires. To this end the study considered the electricity demand by the cattle farms as well as electricity and heat demand from the biogas plants. The biogas plants in average consume 10% of the total power production and 25% of the heat production (Ministry of Food Agriculture and Consumer Protection of Germany, 2012)

To calculate the net electricity and heat generation capacity the study first estimated the total electricity and heat capacity of the plants based on the size of the plants and the electric and thermal power efficiency and assuming the plant works 7500 hours/year (Ministry of Food Agriculture and Consumer Protection of Germany, 2012). After that we calculated the electricity and heat requirements of the biogas plants and the electricity requirements of the cattle farms to obtain the net energy feed in. From the results it can be observed that it is possible to meet 0.57%, 1.16% and 0.33% of the province demand for scenarios 1, 2 and 3 respectively. In total the proposed scenarios could meet up to 2.06% of the province demand with just 1.5% of the total manure produced by the cattle sector in Buenos Aires Province. The net renewable power generation could be used to feed the urban network of the cities that are nearby the plants inside the buffer zones applied in the geographical analysis.

The biogas plants also generated 156.35, 110.65 and 100.05 GW_{th} excess heat for scenarios 1, 2 and 3 respectively. This excess heat could be used in the near future to meet the demand of the nearby dairy farms, greenhouses and public facilities.

	Scenario 1			Scenario 2			Scenario 3		
Technical parameters	Plants ≥250 Kw_{el}	Plants ≥500 Kw_{el}	Plants ≥1 Mw_{el}	Plants ≥250 Kw_{el}	Plants ≥500 Kw_{el}	Plants ≥1 Mw_{el}	Plants ≥250 Kw_{el}	Plants ≥500 Kw_{el}	Plants ≥1 Mw_{el}
Number of potential plants	29	44	17	4	3	39	6	14	13
Total electricity capacity KW_{el}	11643.1	28968.8	25183.6	602.3	2637	129091.2	2278.2	10912.9	29466.3
Substrate demand t/y	323552.685	596146.978	534308.614	27306.392	57534.121	2804345.58	42590.322	238098.162	653933.934
Electric efficiency (%)[a]	38	41	41	38	41	41	38	41	41
Biogas plant electricity requirement [a]	10%	10%	10%	10%	10%	10%	10%	10%	10%
Electricity generation GWh/y [b]	78.59	195.54	169.99	4.07	17.8	871.37	15.38	73.66	198.9
Number of cows	33410	65230	78768	3217	7700	332894	6078	98467	72863
Cattle housing electricity demand GWh/y **	15.14	29.56	35.69	1.46	3.49	150.83	2.75	44.62	33.01
Final electricity feed-in GWh/y	63.45	165.98	134.3	2.61	14.31	720.53	12.62	29.05	165.88
Percentage of province electricity demand covered GWh (%) [c]	0.1	0.26	0.21	0	0.02	1.13	0.02	0.05	0.26
Technical potential heat usage [a]		41%			41%			41%	
Thermal power Generation GWh_{th} [d]		208.47			414.2			133.4	
Thermal power requirement biogas plant [a] GWh_{th}		52.12			13.55			33.35	
Thermal Power feed-in GWh/y		156.35			310.65			100.05	

Table 5. Technical specifications and ratio of power demand covered

a. Electricity requirements obtained from the Federal Ministry of Food, Agriculture and Consumer Protection of Germany, 2012
b. It is assumed that the plant works 7500hrs per year [a]
c. The percentage of electricity demand covered was obtained utilizing the demand of Buenos Aires 63510 GWh and taking out the electricity demanded by the farms and the biogas plants.
d. Calculations were based on plants technical aspects of Madlener et, al (2010).

*The capacity of each plant depends on the amount of substrate available, and changes on the number of plants could be considered depending on the technology available.
** The estimation was made taking into account the total number of cows per scenario and based on the study of the Department for Environment Food and Rural Affairs (2007)

4. Conclusion

This research proposed an optimal site selection method for cattle manure-based biogas plants with the use of GIS land suitability and spatial statistics analysis. The study first defined and identified the restricted areas for the development of potential biogas plants through the use of ArcGIS suitability analysis. After identifying the suitable geographical areas for the installation of biogas plants, the study introduced statistical methods that allowed us to identify the statistically significant spatial clusters at an optimum average distance within groups of farms and finally determine the optimal location, number and scale of biogas plants under the proposed scenarios. We applied the proposed methodology in Buenos Aires Province, the province with the largest cattle inventory in Argentina. The study introduced three scenarios based on the size of the cattle farms: small size (1-500 head), mid-size (501-1000) and large size (1001-more) and for each scenario we designed specific parameters and conditions to obtain the optimum number of biogas plants. The results show that it is possible to install 90 onsite biogas plants for large-scale farms and 46 and 39 CBBP for mid and small size farms respectively. The study then estimated the potential net heat and power generation capacity of the biogas plants and found that it is possible to meet not only the electricity demand of the selected cattle farms, but also up to 2.06 % of the total electricity demand in Buenos Aires by using only 1.5% of the cattle manure produced in the province. Regarding the situation of renewable energy in Argentina, in 2014 only 1.3% of the total electricity production came from renewable sources of which just 4% is related to biogas recovered in landfills (CAMMESA, 2014). The fact that it is possible to reach a similar value with only 1.5% of the total manure generated in the province shows the potential of electricity generation from biogas. There are already successful initiatives in this regard such as the Renewable Energy Sources Act in Germany. Thanks to this initiative the country has the largest number of agricultural biogas plants in Europe (IEA, 2016) and manure already accounts for 43% by weight and 14% by energy output of the feedstock (Scheftelowitz et al, 2014)).

The findings of this study open a great opportunity for the country because it could be possible to both address energy security issues with the use of readily available domestic renewable resources and at the same time reduce significantly the negative environmental impacts of intensive farming. This is important because the recent shift to intensive farming has worsened the environmental problems associated with the poor management of manure and this way it will be possible to give it a more circular nature in terms of reutilization of waste as an energy resource.

The social benefits expected from the use of biogas are also significant. The introduction of this renewable energy could bring energy security and independence and hence contribute to the modernization of urban and rural communities. The initiative could also provide extra income for farmers, enhance resilient communities and promote the creation of new jobs.

However, the implementation of initiatives like this requires strong support from the government. There have been some attempts in this regard. In 2006 the government introduced a law that promotes the use of renewable energy sources for the production of electricity (Law 26190). While the law set a target to produce 8% of the electricity through the use of renewable resources by 2016, its weak enforcement and low compliance made it impossible to achieve the goal (only 1% of the electricity comes from renewable sources). The law has recently been extended and a more detailed plan of action was added setting a target to produce 8% of the electricity from renewable sources by the end of 2017, 12% by the end of 2019 and 20% by the end of 2025. To achieve these goals, the government will introduce incentives for farmers, investors and communities with measures such as the allocation of a special budget of around 800 million USD to promote renewable energy projects. The initiative proposed in this study is in line with the objectives of the law and will be an important factor to achieve its targets.

While the existence of the Law 26190 is an important step in the right direction there are still many challenges ahead. Successful experiences like the effective implementation of the Renewable Energy Sources Act in Germany is an example to follow. This Act established a distributed energy generation model that fixed a purchase price for each type of renewable energy source, and guaranteed grid connection rights. Germany, the country with largest biogas power generation in the world, had less than 2000 agricultural biogas plants with a total installed electricity capacity of around 1000 MWel in 2004 (Luostarinen, 2013) and by 2013, it already had 7874 agricultural biogas plants with a total installed electrical capacity of 3384 MWel, which generated 27 TWh/year (Fuchsz and Kohlheb, 2015). The continuous improvements of the regulations in this country have shown the importance of policies and incentives for the success of renewable energy initiatives. These policies have also shown a positive impact in many other European countries like Italy. This country has successfully applied the technical know-how already developed before by Germany, and introduced the appropriate set of policies and incentives to boost electricity generation from anaerobic digestion. By 2013 Italy was already the third producer of biogas in the world with 7.4 TWh of electricity produced per year by biogas plants with a total installed capacity of 1000 MW (Brizzo, 2015).

This kind of experience could provide important guidelines for Argentina regarding the direction to take in order to promote renewable energy from the agricultural sector.

Finally, as we know, energy generation from anaerobic digestion of cattle manure not only avoids the GHG and pollutant emissions associated with the conventional fossil fuel-based energy production, but also avoids the impacts of current manure management methods applied in Argentina (storage in lagoons and direct spread into soil). Our future task will focus on estimating the overall environmental benefits of introducing this proposal.

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Figure Captions
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Figure 2 Cattle density per department of Buenos Aires Province
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Table Captions
Table 1 Criteria for identifying restricted areas for the siting of biogas plants in Buenos Aires
Table 2 Hub cities in Buenos Aires Province
Table3 Mid-size cities in Buenos Aires Province
Table 4 Size of potential biogas plants and power generation capacity
Table 5 Technical specifications and ratio of power demand covered

Highlights

A geographical model to find suitable areas for biogas plants was proposed.
GIS statistical-suitability analysis is useful for biogas plants location.
Manure based biogas plants can improve the energy security of Argentina.
With 1.5% of the total manure of Buenos Aires, 2% of its power demand can be covered.