VALORISATION OF AGRICULTURAL BY-PRODUCTS IN DIFFERENT AGRO-ENERGY DISTRICTS: A CASE STUDY IN NORTHEAST ITALY

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ABSTRACT: The development of renewable energies requires a preliminary study of the availability of bioresources and their spatial distribution over the territory considered. Special attention must be dedicated to the technical and economic feasibility of the bioresources. The present research aims to perform an analysis of the main by-products available for energy purposes in the Veneto region. This analysis tried to answer the following questions: *i*) which are the primary sources of biomass (crops and livestock) for biogas production? *ii*) how are they distributed in the municipalities? *iii*) what is the share for each municipality of the energy available but not yet used? The analysis showed that the bio-energy potential is 2,38 GWh per year, and the most important sources are maize (*Zea mays* L.): 861 GWh, wheat (Triticum aestivum L.): 428 GWh, livestock by-products: 362 GWh. Considering the present exploitation of these resources by biogas plants, bioenergies can increase their contribution by 39%.

Keywords: agricultural biogas plants, agricultural residues, animal residues, biogas, geographical information system (GIS), methane.

1 INTRODUCTION

International organisations and national governments are increasingly committed to pursuing environmental sustainability policies, setting even more ambitious goals for reducing pollution and the impact of human activities.

The United Nation (UN), has included in the Sustainable Development Goals (SDGs) "… 7. Affordable and clean energy…", [1]. The EU, in the "Renewable energy Regulation", sets the goal of producing 32% of energy from renewable sources by 2030 and reducing greenhouse gas emissions by 40% compared to 1990 [2].

The production of bioenergy obtained from natural and agro-industrial sources represents one of the most critical points of this path. Valorisation of biomass and by-products can help to reduce the employment of land for energy crops. It is essential to avoid competition with food products, but also to minimize the application of agricultural inputs (fertilizers, pesticides, and additional energy) [3], with environmental benefit in terms of Greenhouse Gas (GHG) emissions. In 2016, bioenergy was the most significant renewable energy source globally, covering 70% of the share of all renewable energy sources. In every continent, biomass is the most important source of renewable energy in terms of supply, accounting from between 40% (Oceania) to 96% in Africa [4].

The widespread spatial distribution of agricultural residues with a low energy density and its seasonal variability produces economic and environmental burdens for their logistics [5–7]. These factors also affect the regular supply of fuel for the operation of energy facilities throughout the year on an ongoing basis [8].

Scarlat et al. provided an assessment of the spatial distribution of biogas potential in Europe. The theoretical biogas potential was assessed at 18 billion m^3 of biomethane [9]. Thorenz et al. assessed available agroforestry residues, identifying wheat straw as the most promising source in the agricultural sector [10]. Bernal et al. reviewed the literature about manure compositing. They presented the factors which affect the quality of composts produced: humidification of organic matter, maturity of compost, nitrogen losses [11]. Mirkouei et al. developed a model to determine the environmental and economic effects of the use of biomass [12]. Sahoo et al. developed a GIS-based platform to assess the availability of sustainable crop residues at high spatial resolution (30 m). They used sustainability indicators: soil erosion, soil conditioning index and organic matter factor, to assessing sustainable removal rates of crop residues [13]. Chiumenti et al. evaluated biogas and methane yield from dried and ensiled grass (without conditioning). Dry and ensiled grass reached a biogas yield of 566 and 573 $m^3 \cdot$ton VS, respectively. Compared to the biogas yield of 640 $m^3 \cdot$ton VS of the fresh grass [14]. Franco et al. used GIS and Fuzzy Weighted Overlap Dominance procedure to model the multi-criteria problem of identifying the most suitable locations for biogas plants in an area of Denmark [15]. Patrizio et al. explored the potential role of agricultural biogas in different usage options: gas grid, district heating, electric grid, refuelling station [16].

An adequate definition of the energy potential of an area is the first step to organise a proper exploitation system. The identification of the spatial distribution of the resources allows identifying the optimal location of the biogas plants and the reduction of the environmental and economic costs related to the fuel consumption due to the transport of biomass. In the present study, an assessment of the bioresources in the Veneto region is presented. The analysis considered the agricultural by-products, crops for energy purposes, livestock wastes. Technical parameters were considered in order to establish an adequate value of the energy potential: difficulty in the harvest phase, alternative uses of resources, loss of energy in the conversion phase.

2 MATERIAL AND METHODS

2.1 Data collection

In the first phase, data related to the crops were collected to compute the biomass potential. The regional office for agriculture (AVEPA) provided data concerning the distribution of crops with a resolution at the municipal level. Data concerning to the cultivated areas allowed to determine the available biomass.

Data related to livestock by-products are provided by the national livestock register (ANZ). The acquired datasets were divided into the following categories: animal, livestock system, usage and municipality. Data and categories were then used to estimate the total amount of slurry and manure available for energy production.

Electricity produced by public and private operators and inlet in the electricity grid is managed by the national energy service office (GSE). Available data included the type of used biomass (agricultural, livestock, urban waste), the installed power and the approximated location for all national plants, included those encompassed by the present study. On the basis of these data, the energy potential already used was assessed, and future development could be estimated.

2.2 Treatment of data

Energy potential for main biomasses (for each crop and livestock by-product) was quantified based on different values reported by literature and averaged in case of multiple references. A summary of the most important parameters: Dry Matter (DM), Volatile Solids (VS), methane potential and energy potential, is reported in Table I (crops) and Table II (livestock).

Table I: Parameters for agricultural biomasses

	Yield (t/ha)	DM (%)	VS (% DM)	Methane yield (m^3/t VS)	MJ·t	References
Barley	14,73	26	93	290	2513	[17–19]
Maize	55,6	27	90	450	3950	[17,20]
Ryegrass	24,9	45	90	400	5851	[17]
Sorghum	48,53	34	92	313	3536	[17,18,21]
Soybean	3,50	75	83	196	4373	[18,19]
Triticale	25,3	30	92	440	4386	[17,18,22]
Wheat	30,0	40			3640	[23]
Straw		80	85	250	6140	[20]

Table II: Parameters for livestock by-products

	Total (t/head/year)	DM (%)	Methane yield (m^3/t VS)	MJ·t
Cow (slurry)	9.8	8	200	462
Beef cattle (slurry)	5	8	200	462
Cow (manure)	10.8	20	100	578
Beef cattle (manure)	5.4	20	100	578
Pig-Sow (slurry)	6	5	300	433
Pig (slurry)	5	5	300	433
Pig-Sow (manure)	1.89	20	300	1734
Pig (manure)	1.89	20	300	1734
Poultry (manure)	0.015	20	300	1734

The cultivated area of each crop was multiplied by the yield value to quantify the biomass available. Only municipalities with a minimum value of 1 ha of cultivated area for the considered crop were included in the calculation. For the crops, the Harvest Index (HI) value was used to determine the weight of residues as a percentage of the total DM of a crop [Formula 1]. Methane yield per tonne of total biomass was assessed for each crop: total matter and the related values of DM, VS and methane yield per tonne of VS were multiplied [Formula 2]. Livestock by-products data allowed to determine the amount of slurry/manure for different category of livestock system and usage. The estimated yields were then further reduced by 20% to take in consideration that part of the straw could be applied for other purposes [24]. Considering technical features of the Veneto region, the availability of manure and slurry was estimated in 80% [24]. The energy potential for each municipality was calculated by the relative data of bioresources and by-products and their energy value. Based on the estimated amount of methane yield, the energy potential was calculated by assuming a lower heating value of 36.6 MJ/mc of methane [23]. Combustion processes that use high-efficiency plants with steam turbines to produce electricity can achieve an overall efficiency of 40%; with integrated gasification combined cycle (IGCC) gas turbines, the efficiency can achieve 60% [9,25] [Formula 3].

$$BP_i = \frac{S_i \cdot Y_i \cdot (1 - HI_i)}{HI_i} \qquad (1)$$

Where:

BP_1 is the by-product by the i-th type of crop.
S_i is the area cultivated with the i-th crop;
Y_i is the estimated yield of the crop;
HI_i is the harvest index of the crop.

$$CH_{4t} = B_t \cdot DM_t \cdot VS_t \cdot YCH_{4t} \qquad (2)$$

Where:

CH_{4t} is the methane potential of animal or crop type t [m^3 CH_4 / year].
B_t is the biomass production of animal or crop type t [tonnes total matter / year];
DM_t is the Dry Material content of biomass [%];
VS_t is the Volatil Solid content in Dry Material in biomass [%];
YCH_{4t} is the methane yield of biomass [m^3 CH_4 / VS].

$$E_p = \sum_{t=1}^{n} CH_{4t} \cdot A_t \cdot LHV_{CH4} \cdot \rho \qquad (3)$$

Where

E_p is the energy potential [MWh / year].
CH_{4t} is the methane potential of animal/crop t [m^3 CH_4 / year];
A_t is the availability factor for the amount of biomass that can be collected, depending on crop or livestock [%];
LHV_{CH4} is the Low Heating Value for methane, 36,12 MJ / m^3;
ρ is the efficiency of biogas plants in the conversion of CH_4 in electricity.

The installed power was multiplied by the operating hours per year to calculate the energy produced in biogas plants. Biogas plants need ordinary and extraordinary maintenance; based on data provided, biogas plants operate on average 340 day/year. With this value and the installed power, the energy produced was assessed.

2.3 Process of location of new plants

Based on data reported in the literature, the distance that allows an economic and ecological transport of biomass must be minor than 40 km [5]. This distance allows to cover the area of a province. For this reason, the amount of energy still available and not used and the possible new biogas plants have been assessed at the province level. Provinces are the administration units between regions and municipalities, corresponding to NUTS level 3, in the Nomenclature of Territorial Units for Statistics of the European Union. In each province, the difference between the energy potential and the energy produced was calculated to determine the resources for new biogas plants. Growth potential was assumed to be equally distributed across municipalities.

Biogas plants currently operating are not equally distributed in the region [Figure 1].

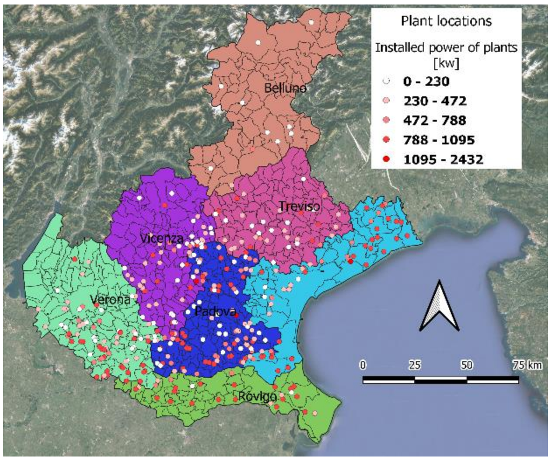

Figure 1: Location and power installed of the biogas plants in the Veneto region.

3 RESULTS AND DISCUSSION

The total energy potential from bioenergy sources was calculated: 2389 GWh per year, 766 GWh from livestock by-products and 1623 from crops.

The primary sources are maize (silage and straw): 861 GWh, wheat (silage and straw): 428 GWh, soybean (silage and straw): 249 GWh, bovine by-products (manure and slurry): 362 GWh and pig by-products (manure and slurry): 319 GWh. Barley, Triticale, Sorghum, Ryegrass and poultry manure supply a total of 169 GWh.

The distribution of bioresources and by-products is not uniform in the region. The areas with the highest potential are those in the South, while the energy potential is lowest in the North, mainly occupied by mountain agriculture. In the South of the region, there is a considerable production of maize and cereals in general. These conditions entail a large availability of agricultural bioresources and by-products. A map with the energy potential was elaborated and showed in Figure 2.

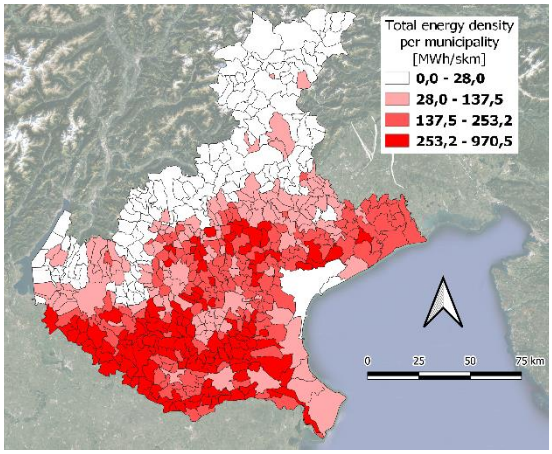

Figure 2: Total energy density per municipality. The energy calculated per each municipality was divided by the corresponding area.

The potential energy from crops and livestock was added to quantify the total potential energy available in each province. Provinces with the highest values were Padova, 534 GWh, Verona, 510 GWh, Venezia, 387 GWh, and Rovigo, 357 GWh [Figure 3].

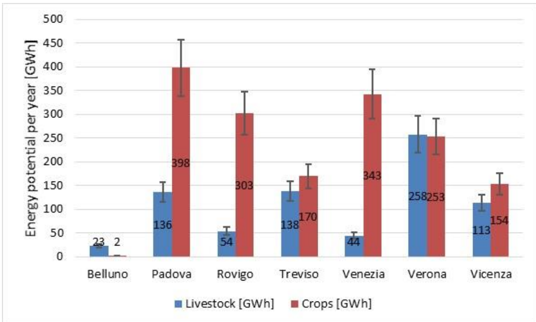

Figure 3: Total potential energy from livestock and agricultural crops in each province of the Veneto region

Values of energy potential were compared with the values of energy production obtained from the data on the installed power in biogas plants.

Areas with high potential usually also have high energy production, but the ratio between the two values is not the same for each province. As a result, the percentage of exploitation in the region is 72%, with potential growth of 39%. The area with the highest percentage of exploitation are Venezia (East): 92% and Verona (West): 82%. Percentage of exploitation in each province was supposed to be constant for the municipalities that are part of it; this percentage was applied to the energy contribution of each municipality.

The outcome was the map of the potential growth of bioenergy exploitation [Figure 4]. The agro-districts with highest potential are Rovigo area (South): 189 GWh, 112% more than the present exploitation, and Treviso area (North): 176 GWh, 134% more than present exploitation.

This analysis allows identifying the macro areas where it is technically convenient to locate new biogas plants. The installed power of new plants can be determined by further and more detailed analysis that also take into consideration economic and operational aspects.

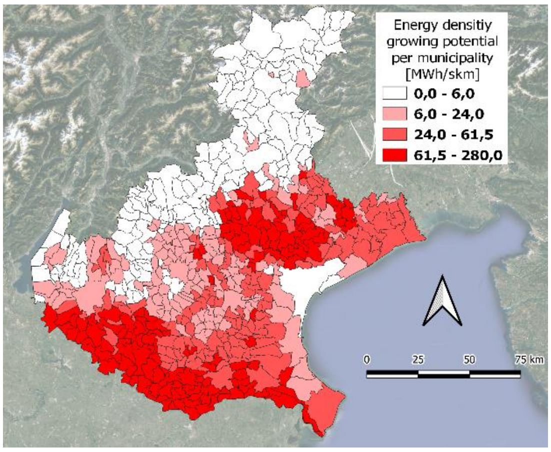

Figure 4: Map of the region with the potential bioenergy growing in each municipality. Values are divided by the area of the municipality.

4 CONCLUSIONS

Preliminary results reported in this study show that bioenergy in the region can increase by 39%, which corresponds to 673 GWh per year. The high potential agro-energy districts can be identified in the South (province of Rovigo) and in the North-East (province of Treviso).

Livestock waste can provide 32% of the energy potential. However, depending on the considered area, the most important sources can be supplied by agriculture (in Rovigo province 86%) or livestock wastes (in Verona province more than 50%). In this study forest biomass and pruning residues were not considered because of their chemical features. Specific plants should be dedicated to this type of resources that are particularly important in mountain areas.

Considering the geographical features and the economic conditions of the Veneto region, agricultural and/or livestock resources can contribute significantly to the production of bioenergy. Further studies can be addressed to not considered sources and to the effects of different scenarios of usage of resources and location of the biogas plants.

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