Biogas from residual grass: a territorial approach for sustainable bioenergy production

A. Mattioli[1], D. Boscaro[2], F. Dalla Venezia[3], F. Correale Santacroce[3], A. Pezzuolo[2], L. Sartori[2], D. Bolzonella[1*]

[1] Department of Biotechnology, University of Verona, Verona, 37134, Italy

[2]Dipartimento Territorio e Sistemi Agro-Forestali (TeSAF)

[3]Bioenergy and Climate Change section, Veneto Agricoltura, Legnaro, 37134, Italy

Keywords: anaerobic digestion, grass, bioenergy, energy balance, economic analysis, Veneto Region

Corresponding author Email david.bolzonella@univr.it, phone/fax +39 045 8027965

Abstract

Large amounts of grass coming from landscape and natural areas management are produced in Europe. This material, which is not competing for land use like energy crops, and is only partially recovered for feeding, can be profitably used for sustainable bioenergy production. In this study it was demonstrated through a GIS based study that this feedstock can be of some interest for the production of biogas in the Veneto Region where more than 100 anaerobic digesters are in operation and feedstock availability can be sometime problematic. Specific field trials showed that costs for grass management are around 30 euros per ton while corresponding CO_2 emission for grass handling (cutting, wrapping and harvesting) are 25 kg CO_2/ton. On the other hand average biogas production of some 500-600 m^3 of biogas per ton (52-56% methane) of volatile solids should be expected. The sustainable production of bioenergy through the proposed approach is therefore feasible.

1. Introduction

Global warming and the necessity to reduce dependency from fossil fuels force society to look for alternative renewable energy sources. Anaerobic digestion (AD) because of its flexibility and capability of producing electric and thermal energy, biofuels (biomethane) and a renewable fertilizer (digestate) can play a major role in the energetic scenario. According to the European Biogas Association [1] there are currently more than 14,000 anaerobic digestion plants running in Europe, 80% of which are treating agricultural feedstocks. AD can be a valuable tool for turning waste and residual material into resources at local level, provided that enough biomass is available for running the plants at reasonable economic and environmental costs.

Landscape and waste grass, because it is not competing with food and feed chains, can be a valid source for feeding anaerobic digestion plants and recovery energy [2]. Several studies demonstrated the possibility to use grass of different origin for energetic purposes via anaerobic digestion: in particular, those studies focused on grass from landscape management [3], meadow grass from nature conservation areas [4,5], grassland [6,7], grass from urban roadside verges [8,9], riverbanks [10]. Grass biomass, depending on its nature, can be co-treated in farm AD plants together with manure [11] or together with biowaste and sludge in industrial AD plants [12,13]. Most of these studies focused on the anaerobic conversion of this biomass into methane but only a few considered a territorial approach so to define the available biomass on a given territory and the environmental, energetic, and economic sustainability of the proposed approach [e.g., 3, 7].

In this study, carried out in the framework of the European project “Grass as a Green Gas Resource - GR3”, we considered the specific situation of the Veneto Region, north-east of Italy, and calculated the biomass available for biogas generation at a Regional level and its energetic content. Moreover, the territorial distribution of anaerobic digesters and the costs for logistic of mowed grass transport were taken into account.

2. Materials and methods

2.1 Experimental design

In the first part of the study we identified the grass available at territorial level for the Veneto Region considering both grass coming from the waste sector (roadside verge, urban parks) and grass recoverable in natural areas, grassland, meadows, riverbanks that undergoes to the by-product regulation. Information on wasted grass were directly collected from Regional databanks while the grass potentially recoverable from landscape was calculated considering the territorial specificity (use of land). The biomass globally available was therefore determined. At the same time anaerobic trials were carried out on grass samples of different origin (public parks and natural areas) to define the biogas potential of grass of different origin.

These information were then combined and a map indicating "energy density" was defined and compared with the territorial distribution of anaerobic digestion plants. The costs for logistic as well as their environmental impact were also considered so to define the global sustainability of the proposed approach.

2.2 Grass sample and biogas potential

Grass samples were grabbed both in public parks in Verona (45.40N, 10.99E) and natural areas in Valle Vecchia, Caorle, Venice (45.63N, 12.95E) an experimental farm managed by Veneto Agricoltura. The average rainfall for the flat part of the Veneto Region is in the range 787-1091 mm/year while the average temperature is 13.2 °C. Grass mowed in Vallevecchia was cut at a size of 0.1 m and 1 m before balling it. This material was left in place for 48 hours before collection so to reduce the water content. Samples of all the different conditions were taken. The same material underwent also to a silage process without enzymes addition (constipation in anaerobic conditions). Also in this case the different samples were taken. Collected samples were characterized in terms of chemical-physical characteristics and biogas potential. Anaerobic batch tests for the evaluation of biogas production (BMP test) were carried out following the methodology suggested in Angelidaki et al. [14]. Biogas was determined in triplicate using 1 L reactors, 0.5 L working volume, sealed with chloro-butyl caps after nitrogen injection for anaerobic conditions. The inoculum used in these trials was obtained from a farm anaerobic mesophilic (37°C) digester usually feed with cow and chicken manure, and mix of energy crops (maize silage, sorghum silage, triticale silage) and straw. The inoculum was filtered at 2 mm in order to remove coarse material and left at 37°C for one week to reach endogenous conditions. The solids content after acclimation was 24.3 g/kg, 73% volatile. The volume of generated biogas was determined by water displacement while its composition was determined using a Geotech Biogas 5000 determining methane percentage and H_2S concentration.

2.3 Data collection on grass availability

The global quantity of available biomass was calculated taking into account both the quantity of grass produced in urban areas and along road and rails, which is a waste, and the grass coming from rural areas and landscape and water courses management which is considered a residual material available for feeding purposes.

With specific reference to wasted grass coming from urban areas all companies involved in waste management are obliged to upload the data regarding the collection of different waste streams into a Regional portal managed by the Environmental Protection Agency of the Veneto Region (ARPAV). On the website of ARPAV (http://www.arpa.veneto.it/rifiuti/htm/banca_dati_ru.asp) it is possible to find data of different types of collected urban waste, reported in tonnes per year and per municipality. As for grass, these data are collected together with clippings, branches, and catalogued with the European Waste Code 20.02.01. The data with code 20.02.01 for the year 2012, referred to the 581 municipalities of the Veneto Region, were collected and then processed. As a first step the data on green waste were transformed into "grass", removing the mass referred to clippings, branches and other ligneo-cellulosic materials. It was roughly estimated that grass represented 90% of the waste with code 20.02.01.

As for the grass potentially recoverable in rural areas or deriving from landscape and water courses management, this was estimated by use of regional maps defining the use of land. The number of hectares covered of grass was determined and a specific yield of 6.5 tons of dry matter per hectare per year was determined. In particular, the grass potentially recoverable in rural areas or deriving from landscape and water courses management, was estimated by use of GIS. The Veneto Region has one of the most detailed map regarding the use of land: starting from the database G.S.E. Land - Urban Atlas then improved by using satellite imagines SPOT 5 (multispectral band 10 m, panchromatic band 2.5 m) and integrating the data with several different databases (TeleAtlas, Roads Map, Numerical Regional Chart, DEM, and forestry maps), a detailed map for the "Land Use" for the Veneto Region was defined. This is a 1:10.000 map with a thematic area with detail of 0.25 ha and 5 levels of "land use" based on the Corine Land Cover nomenclature. The map can be find at http://idt.regione.veneto.it/app/metacatalog/getMetadata/?id=551&isIe=false.

Through this exercise We have therefore individuated the areas (in hectares) dedicated to natural areas, meadows, water courses banks and considered an average production of grass equivalent to 6.5 tonDM per ha per year a value very robust for the Veneto Region and similar to other data present in literature also for other European Regions with similar climate conditions [3,13]. In order to consider a reliable amount of usable grass we than applied a 25% capture rate of this grass available for anaerobic digestion (the rest is normally left in place because of handling costs).

2.4 Energy efficiency of grass valorisation

The energy balance of grass use for anaerobic digestion has been calculated using the gross energy requirement method [18, 19]. In addition, a ratio that estimates the energy return on energy invested (EROEI) [20] has been calculated according to equation (1):

$$EROEI = output energy / input energy \quad (1)$$

The energy output is the product obtained by the conversion of grass into methane. It has been assumed that methane has an energy content of 39 MJ/m^3 [21, 4] while the grass methane yield has been obtained by the BMP trials.
On the other hand, the energy inputs include both the direct, e.g. fuel consumptions, and indirect, e.g. machineries manufacturing, inputs required for the grass recovering and digesting operations [22, 25].
The operations that are required to recovery and convert grass into biogas have been divided in three phases: *grass recovery* (mowing, harvesting, logistic operations and grass storing), *biogas conversion* (grass purification, plant feeding and anaerobic digestion process) and *digestate management* (treatment and spreading).
Concerning the first-phase, for the mowing and harvesting processes, three operative scenarios have been considered:

1. if grass came from the urban waste management, no inputs has been taken into account because these operations are performed independently and often they are accomplished at a household level;
2. if grass came from riverbanks or roadsides a combined mowing-harvesting system has been considered as proposed by [10];
3. if grass came from natural and rural areas a separate mowing and harvesting system with a higher field capacity than the previous scenario was set.

For each scenario, two different logistic distances have been computed: a shorter distance of about 5 km and a higher distance of about 30 km. The energy values has been calculated according to those proposed by [23].
In recovery of grass it has been also considered if grass comes from riverbanks, roadsides, natural and rural areas because while grass from waste management is available daily for the AD plants, grass from these areas is collectable only on determinate periods during the year. Therefore, a silo is required in order to make grass available for AD plants during the year. The energy inputs required for these operations have been calculated according to those proposed by [24].
The direct and indirect energy requirement for biogas conversion of grass has been analysed considering that grass is only 10% of the feedstock in a 1 MW plant. The value of 10% was chosen because of the experiences of some digesters treating grass. A cleaning process has been considered for grass from urban waste management, roadsides and riverbanks because grass could be polluted by materials that can damage the anaerobic digestion plants such as plastics residues, cans, wood, etc.… On the other hand, the energy amounts for the construction of digesters and storage tanks, and the energy required for the heating, pumping and mixing of the digesters have been assumed as described by [26, 21, 25].
An energy value has been also computed for the management of the digestate that is produced as resulting material of the AD process. If grass comes from the waste management and areas such as riverbanks and roadsides a treatment operation is necessary because grass is a waste according to the Italian laws. Again, the spreading distance of the resulting product of the process has been assumed close to the anaerobic digestion plant.

Tab. 1 Energy inputs required for the three operational phases

Operations	Energy input	Unit	Sources
Grass recovery phase			
Mowing and harvesting [b]	799	MJ/t	[10]
Mowing and harvesting [c]	435	MJ/t	[10]
Logistic	35	MJ/t · km	[23]
Storing (ensiling in horizontal silos) [bc]	135	MJ/t	[24]
Biogas conversion phase			
Cleaning of grass [ab]	28	MJ/t	Own calculations
Plant feeding and biogas conversion (electricity and heating)	200	MJ/t	[25, 26]
Construction of AD plant and digestate storage tanks	135	MJ/t	[21]
Digestate management phase			
Waste treatment: composting [ab]	510	MJ/t	[27]
Loading, transport and spreading	75	MJ/t	[22]

[a] Grass from urban waste management
[b] Roadsides and riverbanks
[c] Natural and rural areas

3. Results and discussion

3.1 Grass characteristics and biogas potential

The basic chemical-physical characteristics of collected grass samples from public parks and natural areas and their biogas potential were determined. Grass from public parks is mowed often and the lignin content is low. The corresponding biogas production was some 0.60-0.65 m3 per kg VS. Values up to 0.7 m^3/kgVS were also observed.

As for the samples coming from natural areas (Vallevecchia) also ensilaging was considered in this study.

Grass after mowing was cut at different size (0.1 m and some 1 m) and left in place for 48 hours. After that time grass was harvested and balled. The same samples underwent ensilaging in anaerobic conditions so to verify the effect of this process on the main properties and energy content. The complete set of samples was analyzed and the main results are shown in table 1. The dry and volatile matter content was similar for grass samples of no ensiled grass of size of 0.1 or 1 m. Similar results were also observed for ensiled samples. The dry matter content was around 390 g/kg for samples of 1 m and some 460 g/kg for samples of 0.1 m. Volatile matter was 90% in all cases. On the other hand, when considering samples left in place for 48 hours after mowing, the dry matter content rose up to 900 g/kg because of water evaporation. This is a fundamental parameter for transportation since the amount of grass to be transported and its energy density are largely improved. The COD content is in line with the dry matter content. Nitrogen and phosphorus were at levels of 3-4 gN per kg and 0.4-0.5 gP per kg, respectively. These values increase in the dried samples after 48 hrs on fileds. With specific reference to biogas production the levels were in the range 0.52-0.58 m3/kgVS, with a methane concentration of 53-55%. When considering ensiled samples of 0.1 and 1 m the dry matter content was very similar: concentrations of 382 and 462 g/kg were observed, 90% volatile matter. The samples left in place for 48 hours showed dry matter levels of 916 g/kg. Also in this case COD showed a similar level compared to dry matter. Values for biogas potential were slightly higher compared to those observed fro no ensiled samples exceeding levels of 0.6 m3/kgVS in all cases methane being at 55% on average.

All these results are in line with data reported in literature which are however quite broad. Prochnow et al. [6] reported a considerable number of data for biogas production from grass species collected in different seasons in some European countries. Reported biogas values were in the range 0.299 - 1.080 m3/kgVS. It was emphasized in that study that grass biogas potential can be influenced by climate, latitude, environmental conditions as well as seasonal variations.

Table 2 – Chemical physical characteristics and biogas potential of grass samples of different size

	Fresh grass		
	Fiber > 1 m	Fiber > 10 cm	48h left in place
Biogas, m^3/kgTVS	0.576 ± 0.049	0.526 ± 0.014	0.580 ± 0.001
Dry matter, gDM/kgFM	394 ± 28	468 ± 33	906±63
Volatile matter, gTVS/kgFM	363±25	418±29	829±58
Organic matter, gCOD/kgFM	382±26	453±31	878±64
Nitrogen, gN/kgFM	3.86±0.23	4.59±0.32	8.88±0.56
Phosphorus, gP/kgFM	0.43±0.03	0.51±0.03	0.99±0.07
	Grass silage (30 days)		
	Fiber > 1 m	Fiber < 10 cm	48 h left in place
Biogas, m^3/kgTVS	0.659 ± 0.002	0.618 ± 0.008	0.619 ± 0.002
Dry matter, gDM/kgFM	382 ± 27	462 ± 32	916 ± 64
Volatile matter, gTVS/kgFM	354 ± 25	417 ± 29	833 ± 58
Organic matter, gCOD/kgFM	371±31	448±28	888±65
Nitrogen, gN/kgFM	3.75±0.32	4.53±0.25	8.98±0.57
Phosphorus, gP/kgFM	0.42±0.03	0.50±0.03	1.00±0.06

The profiles of the BMP tests (figure 1) show that trials on "fresh" samples (1a) gave similar results (between 0.5 and 0.6 m^3/kgVS) no matter the cut size, drying and the ensilaging process. The biogas production rate was however quite variable given that material of different length maintains and protects the liquor material in a different manner: material cut at 0.1 m gave a faster response compared to material cut at 1 m (higher SGP after 30-40 days) but with a lower ultimate SGP (90 days). On the other hand, when considering ensiled material differences were smoothed and the SGP was similar on all cases, around 0.6 m^3 per kgVS (figure 1b).

So, despite the number of variables to be considered, results are quite often similar. Comparable results can be easily found in literature: Dandikas et al. [15] presented the data regarding the SGP of more than 40 different grass species collected in different seasons. The average SGP reported in the study gave a value of 659 l/kgTVS with 54% methane content, values very similar to those reported in our study.

Also Nizami et al [16] reported that grass biogas potential is similar for each grass specie because the more easily biodegradable part is the one associated to liquor and humor and this is quite conservative in different grass species.

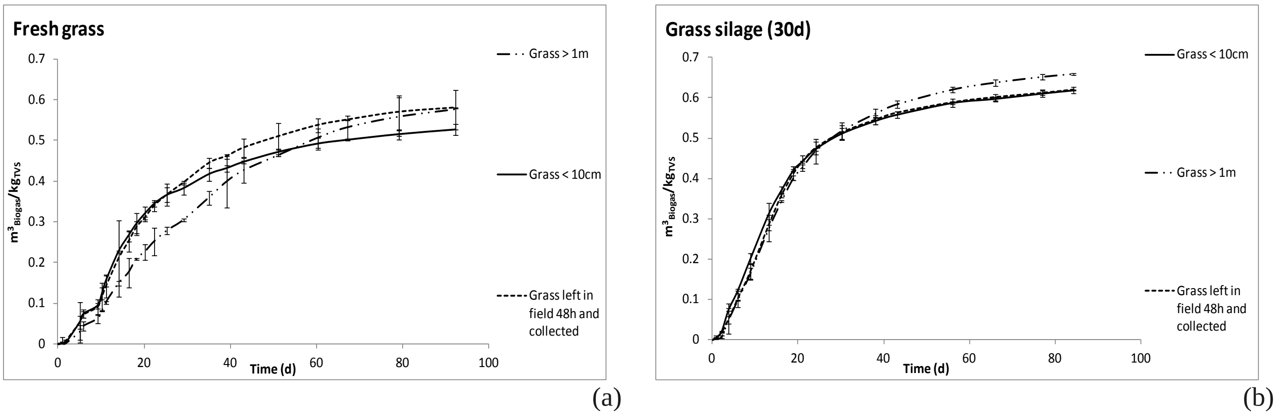

Figure 1 - Biogas production of different samples of grass of different size, fresh (a) and after 30 day ensilaging (b)

Noticeably, the average value observed in our study for grass from natural areas, some 0.560 ± 0.021 m^3/kgTVS, was similar to the one reported in the study of Kosse et al. [13], where the authors reported an average SGP of 0.544 m^3biogas/kgTVS with a methane percentage of 59%. In that study a number of different grass samples coming from different environments like forest, pastures and green urban areas were considered.

These results are however in contrast with those reported in Triolo et al [17] where the SGP was associated with the lignin content and average predicted values were considerably higher (up to 740 l/kgTVS) than those reported in this study and cited papers were data derive from experimental trials.

3.2 Biomass availability and potential energy recovery

The potentially recoverable grass (urban and rural) in tonDM per year was calculated as described in the material and methods section. In particular, a 25% capture yield was considered for this material. These values were associated with the shapefiles of the municipalities of the Veneto Region. The resulting map of grass availability is shown in Figure 2. The productivity is divided into 6 levels: to give an example, a productivity of 1000 tonDM/year corresponds to some 3000 ton fresh matter per year, or 9 ton per day of available grass biomass. This quantity can be considered available for anaerobic digestion in a given municipality. Therefore, in the same map also the location of the anaerobic digester is geo-referenced so to identify the match between high productivity areas and presence of anaerobic digesters. There are currently 13 AD plants for biowaste treatment and 140 agricultural AD plants running in the Veneto Region. In this sense, and considering that the average size of anaerobic digesters in the Veneto Region is larger than 600 kW, only a grass production > 1800 tonDM/year (pale green) can be of some interest for reasonable bioenergy production.

It turns out clear from the reported map that recoverable grass is extremely low in mountain areas in the northern part of the Region but also in the flat central and southern part of the Region where most of the digesters are located. This is in fact a rural area where land is used for crops cultivation or livestock husbandry, therefore land with different uses is very limited. In these specific cases the amount of collected grass is typically lower than 500 ton DM per year and therefore of scarce interest for sustainable bioenergy production. On the other hand, the main cities in the central flat area, namely Venice, Padua, Vicenza, Treviso, Rovigo and Verona, show the main collection yields for wasted grass: typical values of collection of grass are greater than 500 tons dry matter (DM) per year. This result is related to the presence of parks and gardens in these cities. Moreover, in Venice, Treviso and Villafranca (Verona) international airports are present which can partially contribute to grass generation. Other areas with relatively high yields (generally > 500 tons DM/y) are touristic areas located along the Adriatic coast (Venice and Rovigo provinces) and the Garda lake (Verona province) where a number of camping places are present.

Overall, figure 2 shows that there is only a limited number of situations where a relatively high presence of grass is near an anaerobic digester (green dots). However, in some cases digester are located at distances lower than 30 km and can be of some interest for sustainable biogas production.

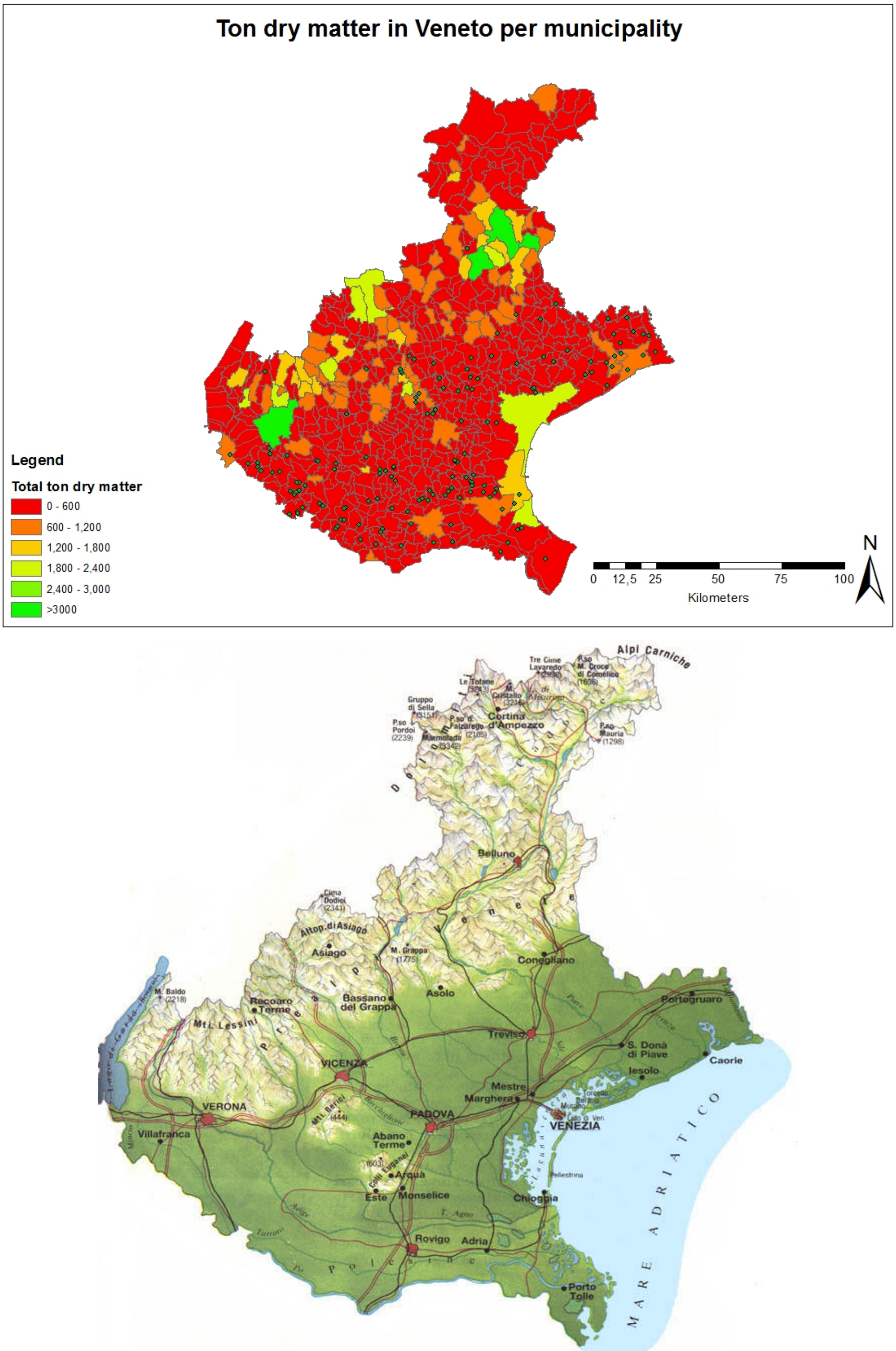

Figure 2 - Dry matter distribution and AD plants location in the Veneto Region (a) and physical map (b)

In general terms, grass is not thought as the single feedstock for anaerobic digestion but, on the contrary, if after mowing and harvesting it is ensiled, it can be used daily like any other energy crop but avoiding any competition for land use. Clearly, the distance of the closest digester is the limiting step, but in such a Region, and given the presence of AD plants, this is not the main bottleneck.

Considering the grass potentially collectable in the landscape management in rural areas or in water courses management, equivalent to 495,000 ton wet weight or 198,999 ton dry matter per year, which can be used in the 140 AD farm plants, and considering a specific biogas production of 500 m^3 per ton DM it can be calculated that some 100,000,000 m^3 biogas per annum can be generated. This is equivalent to some 220,000 MWh of electric energy (33% yield in CHP). This can cover the energy use of some 68,000 families (calculated on the basis of an average use of 3200 kWh per annum per a 3-persons family). On the other hand, some 50 million m^3 of biomethane for the automotive sector can be generated with more than 90% reduction in CO_2 emissions (4-5 gCO_2eq/MJ fuel).

3.3 Energy efficiency of grass valorisation

Table 3 and figure 3 report the energy balance and the influence of each operation over the total energy input Respectively.

In any considered scenario, grass presents a positive net energy gain, highlighting also a positive energy return on energy invested. Although EROEI index isn't particularly high considering other biomasses such as maize [28], greater results are achieved in the waste grass and natural and rural areas scenarios. In this case, when the grass is collected at short distance from the biogas plants, the EROEI ratio is about 4 proving an interesting convenience to collect the grass. On the other hand, the EROEI in the other scenarios is approximately about 2, anyway positive.

Except for the scenario of waste grass at short distance, as shown in the picture of figure 3, grass recovery operations are the input factor that affects principally the total energy efficiency. In fact, more than 50% of energy inputs are influenced by these operations. In particular, the transport distance seems to be the parameter that more impact the grass recovery inputs. Therefore, the transport distance should be as low as possible in order to reduce the energy inputs. Systems that can reduce the transport volumes like round baling or trailers that push-off the product could improve the energy efficiency of the logistic operations. This issue is confirmed by an energetic and economic evaluation of grass handling performed by Boscaro et al. [10]. The study showed average energetic requests of 450 MJ per ton of handled material (cutting, wrapping and harvesting) for a corresponding CO_2 emission of 25 kg CO2/ton and an average costs of 33 € per ton of collected material, confirming the feasibility of the proposed approach when limited distance from anaerobic digesters should be covered.

Table 3 - Energy balance of grass energy valorization

	Urban Waste management		Riverbanks and Roadsides		Natural and Rural Areas	
	5km	30km	5km	30km	5km	30km
Energy output (MJ/t)	4680	4680	4680	4680	4680	4680
Energy input (MJ/t)	1258	2133	2057	2932	1155	2030
NEG (MJ/t)	3422	2547	2623	1748	3525	2650
EROEI	3,7	2,2	2,3	1,6	4,1	2,3

Another important parameter that affect the energy efficiency of grass is the digestate management. The composting treatment necessary when the grass is considered as a waste cause an increase of energy requirements. As consequence, no-polluted areas should be preferably considered and could be more interesting under the energy aspects.

However, a clear legislation that establish when grass is considered as a by-product rather than a waste should solve definitely this problem, giving the possibility to identify which areas of the territory should be utilized for the grass recovery.

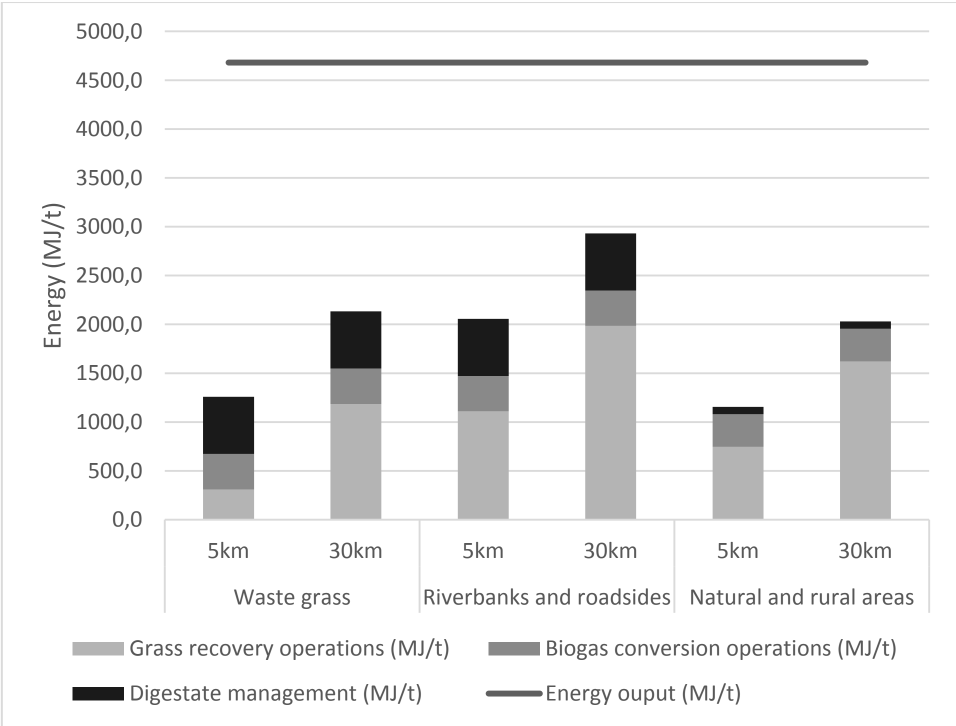

Figure 3: Influence of the several operations over the total energy input

4. Conclusions

The study considered the possibility to use part of the grass produced in natural conservation areas, landscape and river banks management in the Veneto Region for bioenergy production. Results revealed that a good biogas production, typically in the range 500-600 m^3 per ton of volatile solids, can be reached: these yields when associated with a large availability of biomass (more than 500 ton DM per ha per year) and in an area where digesters are present, open the possibility for a really sustainable bioenergy production both from an economic and environmental point of view.

Acknowledgments

“GRass as a GReen Gas Resource: Energy from landscapes by promoting the use of grass residues as a renewable energy resource (GR3)”, IEE/12/046/SI2.645700

References

1. EBA (2015). European Biogas Association Report 2014
2. Singh, A., Smyth, B.M., Murphy, J.D. (2010). A biofuel strategy for Ireland with an emphasis on production of biomethane and minimization of land-take. Renewable and Sustainable Energy Reviews, 14 (1), 277-288
3. Pick D., Dieterich M., Heintschel S. (2012) Biogas production potential from economically usable green waste. Sustainability, 4, 682-702.
4. Meyer, A.K.P., Raju, C.S., Kucheryavskiy, S., Holm-Nielsen, J.B. (2015). The energy balance of utilising meadow grass in Danish biogas production. Resources, Conservation and Recycling, 104, 265-275
5. Tsapekos, P., Kougias, P.G., Angelidaki, I. (2015). Anaerobic Mono- and Co-digestion of Mechanically Pretreated Meadow Grass for Biogas Production. Energy and Fuels, 29 (7), 4005-4010
6. Prochnow, A., Heiermann, M., Plöchl, M., (...), Amon, T., Hobbs, P.J. (2009). Bioenergy from permanent grassland - A review: 1. Biogas. Bioresource Technology, 100 (21), pp. 4931-4944
7. Melts, I., Heinsoo, K. (2015). Seasonal dynamics of bioenergy characteristics in grassland functional groups. Grass and Forage Science, 70 (4), 571-581
8. Meyer, A.K.P., Ehimen, E.A., Holm-Nielsen, J.B. (2014). Bioenergy production from roadside grass: A case study of the feasibility of using roadside grass for biogas production in Denmark. Resources, Conservation and Recycling , 93, 124-133

9. Piepenschneider, M., Bühle, L., Hensgen, F., Wachendorf, M. (2016). Energy recovery from grass of urban roadside verges by anaerobic digestion and combustion after pre-processing. Biomass and Bioenergy, 85, 278-287
10. Boscaro D., Pezzuolo A., Grigolato S., Cavalli R., Marinello F., Sartori L. (2015) Preliminary analysis on mowing and harvesting grass along riverbanks for the supply of anaerobic digestion plants in north-eastern Italy. Journal of Agricultural Engineering, 465, 100-104
11. Frigon JC, Roy C, Guiot SR (2012). Anaerobic co-digestion of dairy manure with mulched switchgrass for improvement of the methane yield. Bioprocess and Biosystems Engineering, 35, 341-349
12. Hidaka T., Arai S., Okamoto S., Uchida T. (2013). Anaerobic co-digestion of sewage sludge with shredded grass from public green spaces. Bioresource Technology, 130, 667-672
13. Kosse P., Lubken M., Wichern M., (2015). Urban lignocellulosic biomass can significantly contribute to energy production in municipal wastewater treatment plants – A GIS-based approach for a metropolitan area. Biomass and Bioenergy, 81, 568-573
14. Angelidaki, I., Alves, M., Bolzonella, D., Borzacconi, L., Campos, J.L., Guwy, A.J., Kalyuzhnyi, S., Jenicek, P., Van Lier, J.B. (2009). Defining the biomethane potential (BMP) of solid organic wastes and energy crops: A proposed protocol for batch assays. Water Science and Technology, 59 (5), 927-934.
15. Dandikas V., Heuwinkel H., Lichti F., Drewes J.E., Koch K. (2015) Correlation between Biogas Yield and Chemical Composition of Grassland Plant Species. Energy & Fuels, 29, 7221-7229
16. Nizami , A.-S., Orozco , A., Groom , E., Dieterich, B., Murphy, J.D. (2012). How much gas can we get from grass? Applied Energy 92, 783–790.
17. Triolo JM, Pedersen L, Qu H, Sommer SG (2012) Biochemical methane potential and anaerobic biodegradability of non-herbaceous and herbaceous phytomass in biogas production. Bioresour. Technol., 125 (2012), pp. 226–232
18. Sartori, L., Basso B., Bertocco M., Oliviero G. 2005. Energy Use and Economic Evaluation of a Three Year Crop Rotation for Conservation and Organic Farming in NE Italy. Biosystems Engineering 91(2):245–56
19. Pezzuolo A., Basso B., Marinello F., Sartori L. 2014. Using SALUS Model for Medium and Long Term Simulations of Energy Efficiency in Different Tillage Systems. Applied Mathematical Sciences 8:129–32
20. Oludunsin A., Voinov A., Van Duren I. 2013. Assessing Bioenergy Potential in Rural Areas: a NEG-EROEI Approach. Biomass and Bioenergy 58:350–64.
21. Prade T., Svensson S.E., Mattsson J. E. 2012. Energy Balances for Biogas and Solid Biofuel Production from Industrial Hemp. Biomass and Bioenergy 40:36–52.
22. Smyth, Beatrice M., Jerry D. Murphy, and Catherine M. O'Brien. 2009. What Is the Energy Balance of Grass Biomethane in Ireland and Other Temperate Northern European Climates?. Renewable and Sustainable Energy Reviews 13(9):2349–60.
23. Boscaro D., Pezzuolo A., Correale Santacroce F., Marinello F., Grigolato S., Sartori L. 2016. Evaluation of different logistic scenarios in riverbanks grass harvesting for biogas plants feeding. Communications in Agricultural and Applied Biological Sciences, In press.
24. Pezzuolo A., Boscaro D., Marinello F., Sartori L. 2016. Alternative maize ensiling techniques for anaerobic digestion process: an economic and energetic comparison. Engineering for Rural Development. In press
25. Meyer A. K. P., Raju C. S., Kucheryavskiy S., Holm-Nielsen J. B.. 2015. The Energy Balance of Utilising Meadow Grass in Danish Biogas Production. Resources, Conservation and Recycling. 104 (2015) 265–275
26. Berglund M., Börjesson P. 2006. Assessment of Energy Performance in the Life-Cycle of Biogas Production. Biomass and Bioenergy. 30(3):254–66
27. Pöschl M., Ward S., Owende P. 2010. Evaluation of Energy Efficiency of Various Biogas Production and Utilization Pathways. Applied Energy. 87(11):3305–21.
28. Gerin, Patrick A., François Vliegen, and Jean-Marc Jossart. 2008. Energy and CO2 Balance of Maize and Grass as Energy Crops for Anaerobic Digestion. Bioresource technology 99(7):2620–27.