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Case Study of Potential Production of Renewable Energy Sources (RES) from Livestock Wastes in Mediterranean Islands

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The aim of this work is to evaluate the potential production of Renewable Energy Sources (RES) from livestock wastes that are commonly found on Mediterranean islands, by using the island of Malta as a case study.
Organic wastes in the form of livestock manure and slurry, as well as other by-products originating from the food transformation industry in the making of alcoholic beverages and the processing of olives, tomatoes and other streams, if mixed in such a way to achieve a correct C/N ratio, can be subjected to anaerobic co-digestion for the production of biogas and digestate. Biogas can be further transformed into biomethane, a fuel that can be used to power surface transportation and agricultural machines, producing heat through burners, or co-generating electric and thermal energy through Combined Heat and Power (CHP) plants. Moreover, the digestate, if treated and transformed into a dry form, can be applied to soils as biofertiliser.
Anaerobic co-digestion process can be compatible with the zero km / zero landfill concept.
The statistical data on livestock populations and herd sizes published by the National Statistics office of Malta were evaluated so as to compute the Maltese potential production of biogas and, indirectly, biomethane or electric and thermal energy.
The results indicate that the Maltese potential production of biogas is 17,942,115 m^3, from which 10,092,230 m^3 of biomethane could be extracted or 1974 MWh ca. of electric energy and 2072 MWh ca. of thermal energy could be generated. Instead, the application of the obtained digestate would be limited by: 1) Nitrates Directive (maximum rate of 170 kg ha^{-1}); 2) fertiliser plans; 3) soil properties such as pH (in the calcareous soils, very common in Malta, differently from acid ones, the nutrients included in the digestate tend to generate insoluble compounds, instead of being absorbed by plant roots); 4) window for application (March-October); 5) local laws that deal with the application of fertilisers (this may be a restriction for the use of wet digestate in Malta, since fertilisers having dry matter less than 30% cannot be applied to Maltese soils).
This work demonstrates that the production of RES, i.e. biomethane, electric and thermal energy, from organic wastes can also have a significant added value, because the potential additional income would include that derived from the sale of biomethane or electric and thermal energy. Furthermore, it should be quantified also the income from the savings obtained by replacing chemical fertilisers with digestate.

1. Introduction

The Mediterranean basin has a complex geography involving a continuous shoreline that extends over three continents engulfing a multitude of islands. The coastline of the Mediterranean basin together with the

habitable islands (162 that are larger than 10 km^2) is home to an estimated 430 million people. The abundance of cultural heritage and tourist destinations attracts a further estimated 300 million tourists per year. Whilst the majority of the population and tourist activities are concentrated in the coastal zones, an estimated 10 million people live in the islands.
Generally the islands have challenging geo-physical characteristics that significantly compromise crop yields, by obliging residents to heavily rely on imported grains, in order to meet their calorific and nutritional needs and that of their livestock. Therefore, based on the fact that these islands are highly dependent on the importation of cereals, there is an urgent need to manage the nutrients of exogenous origin in animal husbandry farms. These nutrients tend to be in excess to what the land can absorb in accordance to sustainable principles: the nutrient amounts that are not absorbed by cultivated plants risk being leached into aquifers and, therefore, contributing to water eutrophication. Furthermore, these islands also depend on significant importation to meet any other need of the resident population and the seasonal influx of tourism.
The technology for the conversion of biomass into energy is well established, especially in the Nordic countries, that have an abundant supply of naturally occurring biomass. In spite of these success stories, the Mediterranean basin has lagged behind. In fact, the recommendations of the Committee on Energy, Environment and Water deriving from the 8th Plenary Session of the Parliamentary Assembly of the Union of the Mediterranean (that was held in Rabat, Morocco, in 2012) focuses on the potential use of biomass in the Mediterranean countries. The Committee concluded that:

1. there is scarce in-depth analysis on biomass availability and its potential use in the Mediterranean basin;
2. the Mediterranean basin is lagging far behind in Renewable Energy Sources (RES);
3. studies are needed on the potential use of biomass in the islands of the Mediterranean basin; these investigations have to focus on:
   a. the impact of the unique characteristics of the above islands;
   b. the extent to which the use of biomass is comparable with other energy sources, such as solar one;
   c. which consequences and impact the use of biomass will have on the ecological, social and economic conditions in the islands;
   d. the extent to which biomass could significantly contribute to existing plans, including already established energy sources.

For this purpose, the Committee on Energy, Environment and Water of the Parliamentary Assembly of the Union of the Mediterranean suggests to carry out applied research aimed at adapting solutions to the Mediterranean basin (on a country/region specific basis), by taking into consideration also the significant amounts of agricultural and livestock wastes generated.
In Malta the exploitation of biomass resources may be feasible for the production of biogas (a combination of CH_4 and CO_2) through Anaerobic Digestion (AD), and/or syngas (a combination of CO_2, H_2O, CO, C_2H_2, C_2H_4, C_2H_6, C_6H_6, etc.) through pyrolysis (Comparetti et al., 2011), i.e. the combustion of the generated waste wood (e.g. unwanted items originating from households, carpenter's offcuts, orchard and garden pruning, packaging materials).
The aim of this paper is to evaluate the potential production of Renewable Energy Sources (RES) from livestock wastes, i.e. manure and slurry, in Mediterranean islands. The Maltese archipelago, characterised by a high population density, a livestock sector totally reliant on the importation of grains and other feedstuffs and a heavy influx of imported goods for meeting the demand of the local population and seasonal tourists, will be used as a case study.

2. Materials and methods

The statistical data about the number of animals bred has been assessed in this study, in order to compute the potential production of biogas and, indirectly, biomethane or electric and thermal energy through Combined Heat and Power (CHP) plants, in Malta.
The numerical data on livestock population, for each considered species (swine, bovine, avian), was retrieved from the report "Agriculture and Fisheries 2014", published by the National Statistics Office of Malta (2016).
The mass of manure produced by each livestock species has been computed by considering the mass of manure produced by each animal type unit and the number of animals (Comparetti et al., 2012, 2013b).
The potential biogas production (B_m) from animal manure has been determined according to the following Eq. (1):

$$B_m = b_m \cdot m_m \tag{1}$$

where: b_m specific biogas yield of manure and slurry mass unit, m^3 t^{-1};
m_m manure and slurry mass of each animal type, t.

Based on the b_m of swine (15 m^3 t^{-1}), bovine (80 m^3 t^{-1}) and avian (84 m^3 t^{-1}), the B_m was computed (Du Pont Pioneer, 2016).
The potential m_m available was estimated by using acceptable conversion factors from University of Wisconsin-Extension (Petersen, 1987).
The yearly electric energy potential production from animal manure E_{em} has been determined according to the following Eq. (2):

$$E_{em} = B_m \cdot e_{eb} \quad (2)$$

where e_{eb} electric value of biogas, depending on the concentration of methane in biogas, kWh m^{-3}
The yearly thermal energy potential production from animal manure E_{tm} has been determined according to the following Eq. (3):

$$E_{tm} = B_m \cdot e_{tb} \quad (3)$$

where e_{tb} thermal value of biogas, depending on the concentration of methane in biogas, kWh m^{-3}
The yearly biomethane potential production from animal manure M_b has been determined according to the following Eq. (4):

$$M_b = B_m \cdot m_{mb} \quad (4)$$

where m_{mb} biomethane content inside biogas volume for each manure type, %, that was considered as 56% for swine and bovine and 58% for avian (Petersen, 1987).

3. Results and discussion

The numerical data of Maltese livestock population are shown in Table 1.

Table 1. Numerical data of livestock population by species and type in Malta.

Swine						
	Piglets < 20 kg	Growing finishing pigs	Breeding sows	Replacement gilts	Breeding boars	Total
	11,022	31,829	3781	564	269	47,465
Bovine						
	Cattle < 1 year		Cattle 1-2 years		Cattle > 2 years	Total
	4483		3165		7235	14,883
Avian						
	Laying hens			Broilers		Total
	297,188			616,974		918,426

AD plants were considered for the production of biogas. Biogas can be treated to separate biomethane from CO_2. The yearly potential production of RES from the biomass generated from livestock activities is shown in Table 2.
The results indicate that the Maltese potential production of biogas (B_m) is estimated at 17,942,115 m^3, from which 10,092,230 m^3 of biomethane (M_b) could potentially be extracted or 1974 MWh ca. of electric energy (E_{em}) and 2072 MWh ca. of thermal energy (E_{tm}) could be generated.
Table 2 shows that in Malta the exploitation of biomass resources has a better feasibility for the production of biogas, leading to the extraction of biomethane. Biomethane is a fuel that can be used to power means of transportation and agricultural machines and also to generate heat through burners or co-generate electric and thermal energy through CHP plants (Comparetti et al., 2015).
Moreover, the digestate can be applied to soils as organic fertiliser within both conventional and organic farming in substitution of chemical ones, sometimes after being transformed into pellets.
In such a scenario, therefore, the AD process can be compatible with a zero km / zero landfill concept.
The geophysical properties and the smallness of the Maltese territory challenge agriculture.
Animal husbandry, contrary to plant agriculture, generates biomass in the form of manure and slurry and spent litter/bedding in steady enough quantities that may merit consideration as candidates for inclusion in a variety of technologies or technology mix for transformation. Using animal manure as fuel offers options to large livestock and poultry operations. The current state of affairs in Malta is posing significant challenges associated with the sustainable disposal of manure and slurry. These challenges could be minimised by considering manure and slurry as components within a circular economy model and integrating them as substrates for the production of RES. In addition, such a process will minimise odours, insect populations, run

off and other nuisances that may be associated with large animal and chicken farms. Ultimately, using animal manure as fuel may improve the financial bottom line of farm operations and contribute to the sustainability of the sector.

Table 2. Production of livestock wastes (manure and slurry) and Renewable Energy Sources (RES) in Malta.

	Swine	Bovine	Avian	Total
Head number	47,465	14,883	918,426	
Waste production/head/day (kg)	6.86	32.05	0.08	
Waste production/day (kg)	325,392	476,996	72,808	875,196
Waste production/year (t)	118,768	174,104	26,575	319,447
Biogas production/day (m^3)	4881	38,160	6116	49,156
Biogas production/year (m^3)	1,781,519	13,928,296	2,232,300	17,942,115
Biomethane production/day (m^3)	2733	21,369	3547	27,650
Biomethane production/year (m^3)	997,651	7,799,846	1,294,734	10,092,230
Electric energy production/day (kWh)	535	4179	694	5408
Electric energy production/year (MWh)	195.11	1525.42	253.21	1973.74
Thermal energy production/day (kWh)	561	4388	728	5677
Thermal energy production/year (MWh)	204.87	1601.69	265.87	2072.42

Different technologies are available to treat various types of manure and slurry, as well as sufficient volumes are needed to make a project viable. AD uses manure for producing biogas having a heating value of approximately 22-30 MJ/m^3, 60 to 80% of the energy value of natural gas.

The volume of waste necessary for a successful energy project depend on the type of waste produced on farms. Manure and slurry having high moisture content (over 75% or conversely 25% of total solids) are generally processed through AD technology, while drier waste may be burned (combustion) or gasified (pyrolysis). Manure and slurry as excreted are generally too wet to burn, but they can be dried through combustion process or mixed with bedding materials to reduce its moisture content.

Animal husbandry in Malta involves various housing and management practices that allow to collect various forms of biomass (Table 3). The different forms will dictate the treatment protocols and identify the most suitable technology to be adopted.

Table 3. Influence of livestock housing on the form of waste collected in Malta.

Species	Housing	Waste form
Swine	slats (farrow finish)	slurry stored in pits under barns
Bovine	solid floor	manure (highly valued as a suitable fertiliser)
	slats	slurry stored in pits under barns
Ovine	solid floor	manure (highly valued as a suitable fertiliser)
Caprine	solid floor	manure (highly valued as a suitable fertiliser)
Poultry	cages	wood shavings (broilers), manure (layers)
Lagomorpha (rabbits)	cages	manure

Sheep, goat, poultry, rabbit and horse wastes can have low moisture content (total solids higher than 25%), particularly if the manure is mixed with bedding. When this type of manure is collected mixed with bedding or scraped, direct combustion or gasification is the best conversion option. Yet, poultry manure contains high levels of uric acid that can damage burners or gasifiers, so diluting this compound by mixing the above manure with other biomasses could be considered. In the case of slurry (having a content of total solids lower than 25%), AD would be the most appropriate conversion technique. In this case, slurry or semi-solid waste must be free of large amounts of other materials, such as rocks or straw and bedding.

It is essential to point out that the primary principle of animal nutrition is based on the least cost formulation of diets that allows to maximise the expression of the animal's genetic potential for growth or milk production. This statement means that the primary role of feed ingredients is to meet the requirements of the animal, and the larger the calorific difference between what is ingested and what is defecated the better use of the diet by the animal, hence the poorer biogas generation by the resulting slurry. The locally produced roughage is harvested at such a late stage that most of the stems would be mature and lignified; hence it is straw and not hay. Straw is very resistant to microbial action. The AD option can be used with any type of manure: it is the manure management practice that is the key to make the final decision on the appropriate conversion option.

Other Mediterranean islands that have a similar tradition of harvesting roughage with the intention of maximising bulk while compromising the nutritive value will experience similar situations.
Since the manure is very manageable and easily quantified, it is highly valued as a fertiliser and actively incorporated into soils. The huge challenge is the management of slurry, that involves 100% of swine farms and a significant number of cattle operations. Due to its liquid state, this slurry is prohibited by law from application on land in Malta, since the whole territory is defined as a nitrate vulnerable zone and hence is not compliant with the Nitrates Directive.
Therefore, slurry from swine and dairy operations could be addressed to be transformed through AD process. Animal husbandry in Malta is not land based, and space on holdings is scarce. Challenges will be encountered when designing systems due to limited space, furthermore the end product of AD process is a nutrient rich effluent that would still have to be managed in a sustainable way, .
The AD process will remove part of the carbon content included in the manure and slurry to convert it into biogas. However, there will be a residue left in the digester. This process, through microbial activity, releases the important nutrients that are locked up within the organic matrix. Thus, the Nitrogen and Phosphorus, the principle elements involved in plant nutrition, shift from a plant-inaccessible organic phase to an inorganic phase that is very readily taken up by plants. The most common forms of Nitrogen and Phosphorus included in the digestate is Ammonium (NH_4^+) and Phosphate (PO_4^{3-}). Plants have an energetic preference to use ammonium, leading to a potential increase of crop yield.
The consistency of this digestate is that of a viscous slurry. It is considered as an ideal fertiliser easily spreadable on farmland. The allowed period for the spreading of this digestate in Northern European countries is between March and October. Yet, in Malta, differently from Northern Europe, the soils are predominantly alkaline, so that this difference in soil pH between the two realities can be an issue for evaluating the suitable technology in relation to the absorption and availability of Nitrates derived from the processing of livestock slurry.

4. Conclusions

The activity of breeding pigs, cattle, sheep, goats, poultry, rabbits and horses results in the production of manure and slurry on a daily basis. This stream produces biomass in a consistent and continuous manner and hence is a likely eligible candidate for consideration for transformation. Traditionally, manure disposal was an integral part in soil management. Unfortunately there are limits in Malta as to how much manure can be spread on land. This practice is associated with some negative environmental impacts. Nowadays manure incorporation into soil is defined and closely regulated and monitored, resulting in an accumulation of nutrients on farm, exceeding the soil storage capacity (e.g. Cationic Exchange Capacity - CEC). Once livestock operation gets to the point when land application can no longer use all the manure, the operator needs to look for disposal alternatives. The transformation of biomass into energy by using appropriate technology or technology mix is a possible option for the local animal husbandry sector. This sector is currently dealing with the excess of nutrients that are continuously generated and accumulated on farm, according to the principles of sustainable animal husbandry. The sufficient livestock population and the quality of the biomass produced are real issues that will be encountered when designing such systems on farm. Alternatively, a low cost off farm centrally located fuel biorefinery having the capacity to carry out the transformation of biomass, e.g. manure and slurry, may be established for the generation of bioenergy.
AD systems determine the following benefits:

1) control of odours, because the volatile organic acids causing the odours are broken down or digested by methane produced by bacteria;
2) minimisation of potential water pollution from the waste, because of the biochemical conversion caused by bacteria;
3) destruction of more than 99% of pathogens, viruses and other disease-causing organisms;
4) conversion of 70% of the organic nitrogen included in the manure and slurry into ammonia, a primary constituent of commercial fertilisers (Comparetti et al., 2013a).

This work demonstrates that the production of RES, i.e. biomethane, electric and thermal energy, from organic wastes allows the extraction of an added value. The extra income generated would include the sale of biomethane or electric and thermal energy and would also allow savings by replacing chemical fertilisers with the nutrient rich digestate. Furthermore a potential subsidy can be gained for producing biomethane as fuel to power transportation.
This work aims at promoting the use of biofuels that are produced locally within the public transportation in seaside areas, characterised by high level environmental sensitivity and high tourist intensity. This case study was applied to Malta, that could cover at least part of the energy demand of public means of transport, through the local production of biogas and, therefore, biomethane, that is a fuel for internal combustion engines.

Malta has already embarked on a number of programmes for better waste management, so that the use of biogas could be seen as a further improvement. In fact, the AD process would allow to indirectly generate electric energy, while enhancing waste management practices, as well as making it more economically feasible (Comparetti et al., 2014).
Therefore, this work contributes to:

- reduce the dependency from fossil energy sources and develop the technology for producing energy from renewable sources;
- reduce the polluting emissions and energy production costs;
- dispose waste through an environmentally friendly method;
- develop new profit sources, through the evaluation of the potential energy available, based on the estimated amounts of residual biomass in Malta;
- reduce the dependency from chemical fertilisers and increase the availability of organic ones, e.g. digestate, able to improve both the chemical and physical soil fertility.

Furthermore the management method proposed in this study for livestock wastes can be applied also to other islands of Mediterranean basin (e.g. Balearics, Cyprus, Crete), where animal husbandry is not land based, appropriate disposal areas are limited and the removal by transport overseas would be very expensive. On the contrary the implementation of AD process could allow to reduce the dependency from fossil energy sources and, at the same time, and produce a very useful source of nutrients and water for local agriculture.

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Reference

Comparetti A., Febo P., Greco C., Orlando S., 2011, Prime prove di un prototipo di pirolizzatore per la produzione di biochar, Atti del Convegno di Medio Termine dell'Associazione Italiana di Ingegneria Agraria, Belgirate (VB), 22-24 settembre 2011, 1-7.

Comparetti A., Greco C., Navickas K., Venslauskas K., 2012, Evaluation of potential biogas production in Sicily, Proceedings of the 11th International Scientific Conference "Engineering for Rural Development", Jelgava, Latvia, 24-25 May 2012, 555-559.

Comparetti A., Febo P., Greco C., Orlando S., 2013a, Current state and future of biogas and digestate production. Bulgarian Journal of Agricultural Science, 19 (1), 1-14.

Comparetti A., Febo P., Greco C., Orlando S., Navickas K., Venslauskas K., 2013b, Sicilian potential biogas production, X Convegno Nazionale di Ingegneria Agraria, Viterbo, 8-12 settembre 2013, Journal of Agricultural Engineering, XLIV(s2):e103, 2013, 522-525, DOI: 10.4081/jae.2013.s2.e103

Comparetti A., Febo P., Greco C., Navickas K., Nekrosius A., Orlando S., Venslauskas K., 2014, Assessment of organic waste management methods through energy balance, American Journal of Applied Sciences, 11 (9), 1631-1644, DOI: 10.3844/ajassp.2014.1631.1644

Comparetti A., Febo P., Greco C., Orlando S., 2015, Italian Potential Biogas and Biomethane Production from OFMSW, IV International Conference Ragusa SHWA on "Safety, Health and Welfare in Agriculture, Agro-food and Forestry Systems", Lodi, Italy, 8-11 September 2015, 206-215.

Du Pont Pioneer, Servizio Agronomico Pioneer Italia, Gruppo E.F. Tecnologie Srl, 2016, Gadesco Pieve Delmona (CR).

European Commission, 1991, Directive of the Council of December 12, 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC), Official Journal of the European Community, Brussels.

National Statistics Office of Malta. Agriculture and Fisheries 2014, 18th January 2016.

Parliamentary Assembly of the Union of the Mediterranean, 2012, Recommendations of the Committee on Energy, Environment and Water of the 8th Plenary Session, Rabat, Morocco.

Petersen J.B., Manure Nutrient Credit Worksheet, 1987, In: K.A. Kelling, Managing manure and waste, Volume 3411 of University of Wisconsin-Extension, Cooperative Extension Service, 1-6.