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Review

European Framework for the Diffusion of Biogas Uses: Emerging Technologies, Acceptance, Incentive Strategies, and Institutional-Regulatory Support

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Abstract: Biogas will constitute a significant fraction of future power supply, since it is expected to contribute a large share of the EU renewable energy targets. Biogas, once produced, can be combusted in traditional boilers to provide heat, or to generate electricity. It can be used for the production of chemical compounds, or fed into a pipeline. This review paper will briefly analyze the current most promising emerging biogas technologies in the perspective of their potential uses, environmental benefits, and public acceptance; draw a picture of current conditions on the adoption of a biogas road map in the several EU Member States; analyze incentive and support policy implementation status and gaps; discuss non-technological barriers; and summarize proposed solutions to widen this energy's use.

Keywords: biogas; biomethane; biological processes; public acceptance; incentive policies; institutional role

1. Introduction

Biogas, defined as a fuel produced through contemporary biological processes rather than by geological ones, such as those involved in the formation of fossil fuels (*i.e.*, methane) will be crucial to the future of global power supply, together with liquid biofuels and intermittent renewable energy sources (wind power and solar photovoltaic). All these will significantly contribute to the decrease of air pollutants and GHG emissions. Overall, biomass is expected to contribute to half of the EU renewable energy targets, as laid out in the Renewable Energy Directive (RED) [1]. Within the bioenergy sector, biogas contributions are planned across all energy sectors: electricity, heating, and transport [2,3]. As part of RED, EU Member States (MSs) must submit National Renewable Energy Action Plans (NREAPs) laying out how they will achieve their binding renewable targets across different energy sectors. Key findings from the latest reports are herein summarized [4]:

(1) At least 10 MSs expect to achieve by 2020 a total surplus of around 2% of total renewable energy (about 64,000 GWh, or 5.5 Mtoe), compared to their binding target for the share of renewable energy of final energy consumption. These surpluses could be transferred to other MSs. Spain and Germany forecast the largest surpluses in absolute terms, with 31,500 and 16,000 GWh, respectively;

(2) Five Member States expect to have a 2020 deficit for a total of about 23,000 GWh (<1% of the total renewable energy needed in 2020). The largest forecasted deficit (in absolute terms) of 14,000 GWh is estimated by Italy;

(3) Overall MSs forecasts for 2020 renewable energy consumption are that the EU should exceed by about 0.3% its established target of renewable energy, fixed at 20% of total consumption.

In the EU-27 alone, more than 1.5 x 10^9 tons of animal manure are produced every year, with a total energy generation potential of about 830 PJ [5,6]. The European Environmental Agency (EEA) estimates that the land potential for environmentally-compatible energy crop cultivation in the EU-27 results in a total additional energy potential of 1115 TWh in 2020 and 1650 TWh in 2030 [7].

By the end of 2014, there were more than 17,000 active biogas plants in Europe, with a total production potential estimated in 770 PJ/year by year 2020, up from 92 PJ/year in 2002: the countries accounting for the largest number of plants are currently Germany and Italy, while the UK is the largest producer of landfill biogas (84% of its national production) [8]. Table 1 illustrates the 2013 production of biogas from different sources in EU countries, expressed in GWh (re-elaborated from [9]). It should be noted that landfill-related production is bound to decrease significantly in the future.

Table 1. Summary of biogas production (GWh equivalents) in EU countries in 2013 (re-elaborated from [9]).

Country	Landfill Gas	Sewage Sludge Gas (Urban/Ind.)	Other Gas (Agric./MSW/Co-Digestion)	Total
Germany	1265.34	4568.264	72,283.94	78,116.38
United Kingdom	17,889.27	3328.506	0	21,217.77
Italy	4777.60	564.055	15,771.44	21,113.1
Czech Republic	336.11	460.548	5844.075	6641.893
France	3256.40	930.4	1221.15	5407.95
Netherlands	286.10	672.214	2562.089	3521.564
Spain	1442.12	346.574	1190.912	2978.443
Poland	718.73	1060.656	1142.066	2921.456
Austria	43.03	213.992	2030.598	2288.784
Belgium	339.60	180.265	1130.436	1650.297
Sweden	158.17	922.259	508.231	1588.658
Denmark	61.64	236.089	865.272	1163
Greece	785.03	187.243	55.824	1028.092
Hungary	166.31	233.763	555.914	955.986
Slovakia	39.54	172.124	564.055	774.558
Portugal	718.73	31.401	9.304	759.439
Finland	368.67	169.798	153.516	691.985
Ireland	501.25	87.225	62.802	651.28
Latvia	213.99	66.291	324.477	604.76
Slovenia	82.57	32.564	288.424	403.561
Romania	17.45	1.163	330.292	348.9
Croatia	24.42	37.216	148.864	209.34
Lithuania	82.57	41.868	55.824	180.265
Luxembourg	1.16	15.119	132.582	148.864
Cyprus	0.00	0	139.56	139.56
Estonia	62.80	20.934	0	83.736
Bulgaria	0.00	0	1.163	1.163
Malta	0.00	0	0	0

The key success factor of the future role of biogas will be the availability of biomass. This of course will depend on several economic, technological, environmental, and regulatory factors (production costs, type of biomass, transport costs, applied conversion technology), which in turn influence biomass sources competition. In the future, a significant share of the resources will be obtained from energy crop production on surplus agricultural land [10].

Flexible energy provision from biogas facilities is currently one of the main technical challenges that needs to be overcome to ensure a complete integration of biogas plants into the energy supply system for the future. Biogas, once produced, can be combusted in traditional boilers to provide heat or generate electricity. It can also be used for the production of chemical compounds or fed into a pipeline for long-distance distribution. Nowadays, the technological aspects of biogas production, although of great relevance and in constant progress, are perhaps less important—in the context of a wider diffusion of this renewable energy source—than other non-technological factors, such as its widespread public acceptance, the availability of state and local incentives, distribution infrastructures, and much needed institutional and regulatory support. These non-technological barriers to biogas diffusion are gradually prevailing to technological ones, slowing down at the same time technological progress.

Studies and EU-funded projects (among the others BIOSURF, FaBbiogas, ESBF, GreenGasGrid, BiogasIN) have highlighted that specific measures and activities aimed at better diffusion on a wider scale of biomass-derived energy should include institutional capacity building, improvement of framework conditions for biogas development, as well as a cross sectorial biogas collaboration and communication networks, optimization of business models, and project financing [11].

This paper will briefly overview current biogas technologies and, in the perspective of sustainable energy projects' potential public acceptance, draw a picture of general EU-wide conditions on the adoption of a biogas road map in the MSs, analyze gaps in their implementation and incentive policies, and summarize proposed solutions to widen the diffusion and use of this energy.

2. Biogas Production Technologies

Thanks to support measures for renewable energies, biogas production technologies have made substantial progress in recent years. As a result, some several thousand facilities are now operating in Europe treating a variety of substrates (feedstocks) such as wastewater, sewage sludge, animal manure, energy crops, municipal organic solid waste, or a combination thereof (co-digestion). Recovery of energy as gaseous biofuels from these sources is mostly based on biological processes.

2.1. Biological Processes

Anaerobic digestion (AD) consists of a sequence of biological processes in which microorganisms break down biodegradable organic material in the absence of oxygen. One of its end products is biogas, which is combusted to generate electricity and heat, or can be processed into renewable natural gas (biomethane) and transportation fuels; the other is digestate, the residue of the process, that might still have intrinsic residual value (nutrients, materials, and energy). Countless species of microorganisms operate this conversion where biogas (and energy) yields depend on: biodegradability of the substrate, type and mix of raw materials, methods of feedstock pre-treatment (chemical, steam, enzymatic, mixing), reactor environment, levels of nutrients for bacterial growth, pH, temperature, and climate.

A typical anaerobic digestion biogas generation plant may look like the one schematized in Figure 1. It is beyond the scope of this paper to enter into the details of these systems, as several review papers on this topic have been already recently presented in the literature [12,13]. These plants are traditionally used for processing the substrates mentioned previously with excellent levels of consistency, although some operational drawbacks are still reported (most commonly, odor generation) [14].

In addition, all existing Municipal Solid Waste (MSW) landfills produce methane-rich gases after closure, and do so for several years, by totally similar processes. Collection and utilization of this biogas is applied widely and in some countries (e.g., Spain, UK) biogas collected from landfills largely overshadows production from other sources (e.g., sludges, energy crops, co-digestion). Improved collection (*i.e.*, by landfill "cultivation" techniques) and processing of landfill gases from existing facilities could still increase energy recovery, although this system of waste disposal has been drastically restricted by recent EU legislation, in favor of direct energy and materials recovery technologies.

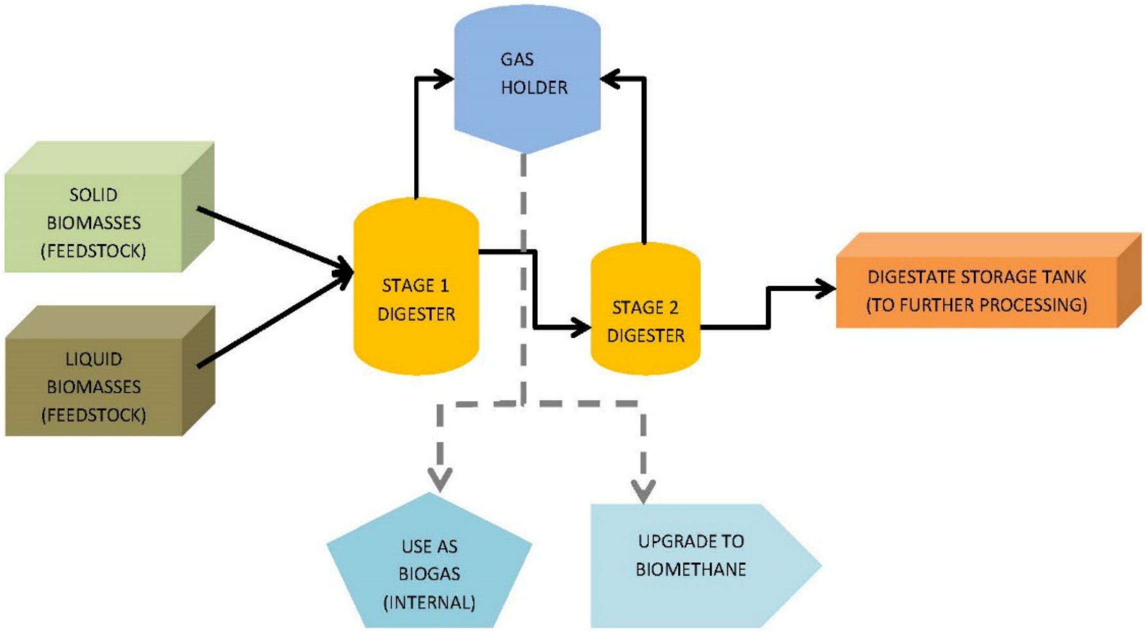

Figure 1. Schematics of a biogas and energy production plant.

2.2. Potential Innovations in Biogas Production Processes

Given the relevance of biogas in future energy strategies worldwide, potential process innovations are constantly pursued by the industry. A significant number of studies have been carried out over the last few years addressing various ways of enhancing, controlling, or optimizing anaerobic digestion, and improving biogas yields and/or quality. Crucial points for improvement of biogas production efficiency are associated with easy access to cheap feedstocks, such as: wastes from agriculture, industry and urban areas, manure, lignocellulosic residues, and cheap (non-food) energy crops. Furthermore, appropriate pretreatment of limited digestibility feedstocks is highlighted as an important step to further increase the access to cheaper raw materials. Processes associated with digestion performance including stirring, mixing techniques, additives (enzymes, trace elements), and control techniques receive considerable attention. Besides these, enhanced and cheaper reactors' designs and improved auxiliary equipment are often proposed [15,16].

2.3. Biogas Uses

Generated biogas can be post-processed removing carbon dioxide, water, and hydrogen sulphide, transforming it into *biomethane* that has a higher heat content, is less corrosive, and therefore represents a more valuable fuel [17]. The most common post-treatments are water scrubber technology and PSA (Pressure Swing Adsorption) technology [18]. After such treatments, the residual gas normally contains more than 97% methane, with possible end-uses that are not different from those of natural gas. The preferred end-use depends heavily on the framework conditions of the site (Country) where production occurred. If electricity generation is favored, raw biogas is usually upgraded to biomethane only if direct onsite production of power and heat from biogas is not possible, or useful. If biomethane is injected into natural gas pipelines, its characteristics (*i.e.*, Wobbe Index) may need to be adjusted, according to current international standards for CNG [19].

Upgrading biogas to biomethane is a relatively new technology, still expensive and, in some cases, not well-known. In some countries (e.g., Spain) biomethane production is considered as a second, optional step, and production of conventional biogas is still the primary aim. In countries where primary biogas production is more diffuse (e.g., Austria, Germany, Switzerland, and Sweden) on the other hand, biomethane production is often advocated, but its market-outcomes may still be immature for large-scale implementation. Generally speaking, an economically feasible upgrading is currently possible only at large-scale facilities, due to applicable technology costs. It follows that biomethane at the moment is often more expensive than natural gas.

After generation and clean-up, biogas can be used in several ways, schematized in Figure 2:

(1) Heating (buildings/industry onsite applications). The gas is combusted in a boiler specially modified/built to combust biogas. The heat generated warms up water (vapor) used to heat the digester, nearby buildings, or it is exchanged on a local district heating network;
(2) Heat-and-Power. Biogas can be used as a fuel in special stationary engines modified for biogas use for co-generation of electrical/mechanical/heat energy;
(3) Motor fuel in natural gas vehicles (NGVs). As vehicle fuel for cars, buses, and trucks, it can be used in lieu of natural gas, provided that it is upgraded to biomethane following automotive standards.

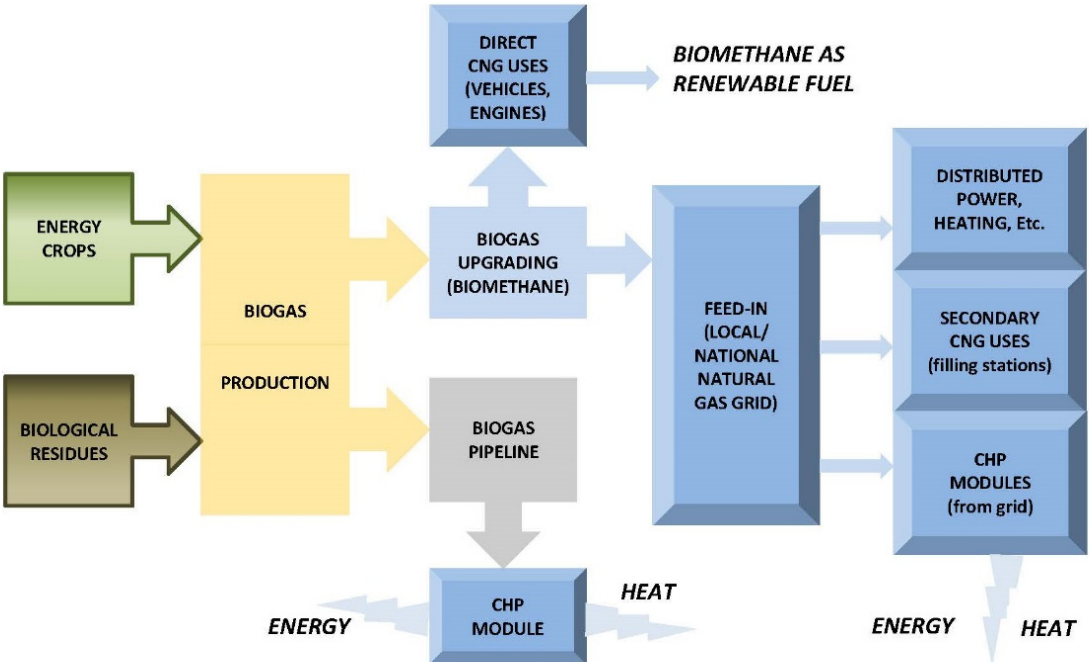

Figure 2. Overview of biogas utilization pathways.

Steubing and colleagues developed an energy system model comprising 13 main fossil-based technologies for production of heat, electricity, and transport to 173 bioenergy conversion routes. Net environmental benefits and financial viability of fossil energy substitution with bioenergy were calculated for over 1500 combinations, based on life cycle assessment (LCA) methodology results. The "best" environmental uses of various biomasses were determined based on different indicators within the EU-27 current energetic context. Optimization almost always indicated that woody biomass is best used for CHP generation when substituting coal, oil, or fuel oil technologies. As far as non-woody biomass, environmental benefits of electricity generation, transportation, and heating were comparable, as long as high conversion efficiencies were assured [20].

Just like conventional (fossil) gas, biogas and biomethane can also be stored and transported, since production of these fuels typically exceeds immediate on-site demand. Storage for future use usually occurs either as compressed biomethane (CBM) or liquefied biomethane (LBM). The cheapest and easiest storage systems are low-pressure ones, commonly used for on-site, intermediate storage of biogas, as such, to compensate for short-term energy demand fluctuations. Energy, safety, and scrubbing requirements of medium-and-high-pressure storage systems make them costly and high-maintenance options for biogas, in fact they are usually adopted for biomethane, due to its higher market value.

In practice, nowadays, most biogas is used just as produced, onsite, for heating, local energy production and, in larger facilities, district heating. Thus, the need for biogas storage is usually of a temporary nature, to compensate lags between production and consumption peaks. Since biogas is a low-grade, low-value fuel, it is not economically feasible to transport it for any significant distance beyond the site where it is generated. Likewise, biogas cannot be economically trucked, considering its corrosive potential. In contrast, upgraded biomethane could be more economically distributed to its point of use by either:

(1) Dedicated biomethane pipelines. This is usually the most cost-effective method for short distances over private property. In this case no specific standards are applicable, other than safety ones;
(2) Natural gas pipelines. In this case, the biomethane producer must negotiate an agreement with the pipeline owner (usually a local/regional gas utility) to supply the product into the line. A fundamental prerequisite is to ensure that the injected biomethane meets the utility's quality (composition) standards. A range of national standards exist in Europe for the injection of upgraded and purified biogas into the natural gas grid [18]. Most likely, resistance will be opposed by the utility toward such a request, due to concerns that poor injected gas quality might have potentially devastating effects on the network's equipment. As a result, severe requirements for gas quality monitoring and fail-safe disconnection of biomethane supply from the network might be imposed. This could lead to prohibitively high expenses for producers, that at the same time must also compete with the (usually lower) wholesale price of natural gas offered by suppliers, unless negotiated prices or incentives are provided by regulations;
(3) Road transport of CBM. This may be used as a temporary solution prior to the installation of a permanent infrastructure, since transportation and capital equipment costs associated make this option generally not sustainable over the long-term;
(4) Road transport of LBM. In addition to its use as a fuel for LNG (Liquified Natural Gas) engines, LBM can be used to fuel CNG (Compressed Natural Gas) vehicles through LCNG (Liquified/Compressed Natural Gas transformation) fueling stations, turning LNG into CNG. Liquefaction of landfill gas has been demonstrated at a number of locations in the USA, but has never been applied to biomethane produced from manure or similar feedstocks. A significant disadvantage of LBM is that it must be used fairly quickly after production (typically within one week) to avoid significant losses by evaporation [21,22].

2.4. Environmental Benefits and Sustainability of Biogas

As the treatment of waste streams is mandatory for industries and municipalities, digestion, generation, and utilization of biogas obtained from those streams can reduce both wastes and their environmental impact, while producing clean energy. This can also help reduce atmospheric GHG emissions, in line with the European Union objectives setting an ambitious GHGs 20% reduction target by 2020, compared to 1990 levels. The actual gain achieved when replacing fossil fuels with biogas depends on the substrate used and other operational factors but, according to current literature, it would be possible to reduce GHGs emissions by at least 70% [23]. Manure-based plants easily achieve such a threshold, however, "averaging" GHG emissions among different co-digested substrates, the use of about 30% (wet mass) maize in co-digestion plants would still allow to achieve such levels.

EU citizens, in general, have a rather vague idea of the overall structure of energy consumption and underestimate, in particular, the amount of energy used for transport. Nearly 90% of individuals consider global warming and climate change serious problems requiring immediate action, and consequently renewable sources of energy tend to get strong public support. Curiously, however, the component of renewable energy in global consumption tends to be overestimated by the public. Although wind and solar sources are commonly identified as the main renewable energy sources, biogas from manure and organic waste is normally perceived as a clean and sustainable option for energy production [24]. The environmental impact associated with anaerobic digestion plants is heavily dependent on many factors, mainly: choice of substrate, technology adopted, and operational practices. On-farm biogas production from manure has shown a high potential to mitigate some of the environmental impacts associated with intensive dairy farming, especially in terms of avoided emissions from traditional manure management, since it is effective in significantly reducing GHG emissions, and substitutes well non-renewable energy consumption. Some impacts, however, (*i.e.*, local photochemical ozone formation) may actually worsen. When energy crops are used as substrates, fossil fuels and chemicals are used for their growth and transport, counting as additional pollutants emissions, together with residue management needs. Feedstock transportation distance strongly influences the overall energy efficiency of the process (PEIO—Primary Energy Input to Output) [25]. The dominant energy crop used for biogas production in most countries is maize, which makes up more than 75% of the crops planted for this purpose. Recently, however, interesting emerging non-food energy crops have been proposed, like *Arundo donax L.* (giant cane, or giant reed), grown with low agronomic input (low, or no irrigation, fertilizers, pesticides, and agronomic mechanical interventions), meaning both low cultivation cost and low environmental impact [26]. Use of low-input, non-food, energy crops as unique feedstock or in co-digestion with manure would also solve the current ethical debate on utilization priorities of food crops [27,28].

Co-digestion of energy crops and manure is an increasingly applied biogas production concept, with rapid growth of plants (especially in Germany) in the past 10 years. Poland, the Baltic States, and Romania are EU countries with large potential for energy crops, forestry waste, agricultural residues that today have a relatively small production. In order to unlock this potential, better organisation of waste streams and a higher penetration of biogas in the power sector seem necessary [10].

The current economic downturn, with dropping energy prices, has a negative effect on all renewable energy sources, even those that are dependent on government support. In order to achieve full sustainability of biogas, some additional economic conditions must be met. At the moment, costs of production are generally above those of natural gas prices, however, biogas can offer intrinsic competitiveness since, in addition to the mentioned environmental advantages, it constitutes a domestic, inherently secure supply compared to natural gas imports from (sometimes) politically unstable extra-EU areas. In order to achieve this, coherent European policies going beyond the promotion of electricity production, and aiming for general oil and coal substitution with biogas (biomethane) should be embraced.

3. Biogas Acceptance in the Current Socio-Political Context

Often, biogas projects involving construction of new facilities are not well accepted by certain local stakeholders (neighbors). This situation is however highly variable in Europe, and also within each country. For instance, results of recent studies carried out in Switzerland show that local acceptance towards existing biogas power plants is relatively high, due to the perceived benefits/costs balance, as well as trust towards plant operators [29]. In other countries, groups of citizens may instead establish local environmental committees specifically to oppose such projects, for reasons ranging from self-interested protection of their own "backyard" (NIMBY syndrome) to different visions of the way to achieve sustainable local development, or combinations thereof [29]. In order to increase the high levels of public acceptance necessary if a substantial increase of new renewable energy projects (REPs) is to be smoothly achieved, the most critical issues at stake should be locally investigated, identified, and addressed. This can be achieved through polls and involvement of consumers, neighbors and local politicians, plant operators and farmers, organic waste producers, biogas equipment designers, investors, and local energy suppliers [30].

Significant research into public acceptance of REPs has been conducted around the world. "NIMBY" (Not In My Back Yard) is commonly addressed as an element of rational choice that ascribes the motivation of human behavior mainly to self-interest, implying that citizens only support REPs if they are built "somewhere else". Empirical evidence, however, suggests that this supposition is generally inadequate, emphasizing the importance of applying more selective approaches in researching local acceptance. An alternative theoretical concept that seems to better explain project opposition cases is *justice theory*. Already successfully used in researching public acceptance of REPs, justice theory, branching into *distributive* and *procedural justice* theory often results in new insights into how projects are perceived at the local level [31], following a multidimensional perspective in which both perceived costs and benefits of facilities, and relevant characteristics of the planning process are taken into account.

Distributive justice theory derives from Adams' equity theory [32], to explain when and why outcome distribution of specific resources (e.g., money, information, services) are perceived by the individuals to be fair, and when they are not. The degree of perceived fairness influences a large number of variables, including outcome acceptance and legitimacy of the process under scrutiny. When dealing with local acceptance of REPs, focus is placed by local residents on costs and benefits as they perceive them, not only in their monetary dimension, but, for example, benefits in terms of creation of employment, tourism, community improvement, and reduced energy costs. In terms of costs, evident examples are: unpleasant smells, adverse landscape impact, constraints/changes on the quality of life (including increased local traffic), in addition to purely economic costs, such as reduced property prices, and tourism decrease.

Procedural justice theory focuses, instead, on how structural procedure characteristics can influence the perception of justice and behavior of authorities towards citizens. In general, the quality of process control (presentation of specific case evidence) and decision control (over the actual case) account for large differences in perceived justice by interested citizens. In the context of REPs, the objectiveness and truthfulness of the information provided, as well as its match to the citizens' level of knowledge and their main concerns, are of great importance. The possibility of changing project parameters to fulfill citizens' requests is relevant for assessing the quality of participation offers, while public involvement from an early stage, although in principle desirable, is often a controversial issue on the part of project developers. The characteristics of project developers and operators, furthermore, have a major impact on public acceptance: in particular, the importance of citizens' trust, both intended as subjective evaluation of their behavior in the present and previous cases, their expertise and competence, as well as of their perceived fairness and responsiveness to local residents' concerns, are all factors that strongly influence the acceptance process.

Soland *et al*. [29] developed a model based on the theories outlined above, implementing structural equation modeling, schematized in Figure 3, and tested it with the aid of specially-designed quantitative surveys, which provided the "weights" assigned by interviewed stakeholders to the relationships between the discriminating factors illustrated in the diagram.

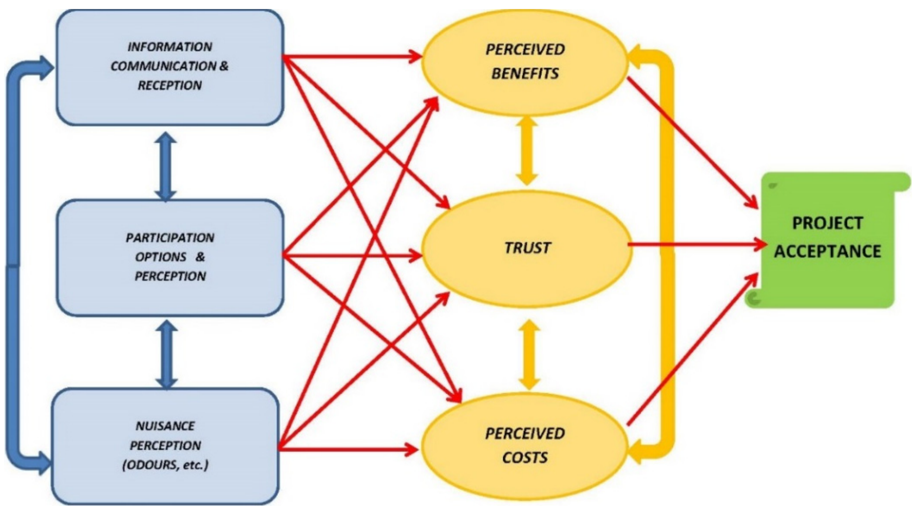

Figure 3. Soland *et al*. [29] model of biogas plants public acceptance.

Application of the model showed that this tool proves to be a reliable method for identifying correlations between discriminating factors influencing local acceptance, allowing a detailed analysis of how different issues such as trust, perceived benefits and costs, information, and participation influence each other in the process, and identifying the most sensitive ones in each situation.

Literature on justice theories and REP acceptance predictors confirms the importance of achieving balanced procedural and distributive justice assessments by citizens to achieve local acceptance of biogas plants. This can be obtained mainly by providing adequate levels of information and participation to residents, and by gaining their trust by planning a fair distribution of outcomes (perceived benefits and costs). In most cases of aborted planning of new facilities, perceived lack of fair distribution of benefits, and distrust towards local authorities and/or plant operators were the main factors of the initiatives' failure [30].

4. National and Local Incentive Strategies for Biogas Use

Installation of biogas plants implies relatively large investments, therefore preferential loans or subsidies covering parts of the initial costs may be important for the implementation of these projects. Investment subsidies exist in almost all EU countries, although this alone does not seem to be a sufficient incentive for initiating a biogas project: well-established regulations and stable income from biogas production are also necessary to determine the pay-back time of the project, making it attractive.

Table 2 (from [33]) highlights existing incentives for biogas production and utilization in three EU countries (Sweden, Germany, and Spain). While there seem not to be a huge difference in the examined countries' situation, comparative analysis with data reported in Table 1, however, reveals that the German absolute production is almost 48 times bigger than that of Sweden (six times bigger on a per-capita basis), 26 times the Spanish one (almost 15 times bigger on a per-capita basis), and almost four times that of its immediate followers in the ranking (UK and Italy). These differences may depend considerably on the actual quantification of incentives and support schemes. So far, Germany has put in place many favorable support measures [10]. In Germany, for example, the feed-in tariff for electric renewable energy production can be up to 10 times larger than that of Sweden, and almost three times the Spanish one [33]. Other factors influencing the diffusion of the technology may include availability of feedstock for co-digestion, considering that the German dairy cow population is about 10 times the Swedish one and five times the Spanish one [34].

Continued discussion regarding feed-in tariff systems in different countries is ongoing [35]. From a strictly socioeconomic point of view, it is argued that such system is inefficient, sometimes promoting production in areas that are not ideal due to lack of nearby users, feedstock availability, *etc*. It is also argued, however, that new technologies (biogas production and other REPs) may not become commercially viable without an initial, stable, prolonged support system. Stability of incentives and tariffs, fixed for 15–20 years is considered of great importance by investors.

New technologies often have problems crossing the so-called "Technological Death Valley", and need protection through Strategic Niche Management (SNM) mechanisms in order to establish themselves solidly on the market [36]. SNM is an approach developed to "understand and influence the early adoption of new technologies with high potential to contribute to sustainable development". Although biogas production and use has been present for decades, its large-scale market introduction as a substitute of fossil fuels can, to all effects, be considered a radical innovation, and related technologies, for all purposes, can be considered immature and at a disadvantage relatively to the incumbent technology (extraction and distribution of non-renewable natural gas), lacking an established network of infrastructure, stable actors, and dominant rules of design.

Since there is a mandated need to develop the renewable energy sector to a considerable extent it can be argued that political and economic measures should be taken to promote those types of productions that do not, at the moment, have the best—or even positive—economic returns. The indirect economic value of job creation, rural development and climate-change avoidance related costs (although difficult to prove and quantify) should also be taken into account. In many countries, Green

Certificates (substitutes to feed-in tariffs) are granted for REPs in order to make them more profitable, but these are usually dependent on the market, and do not necessarily imply the above discussed stability, as it was recently the case in Italy. Differential taxation on fossil fuels could also constitute and indirect competition benefit for REPs [37].

Table 2. Incentives for biogas production and utilization in three EU countries (from [33]).

Economic Support Measures	**Germany**	**Spain**	**Sweden**
Investment subsidies	Yes	Yes	Yes
Investment loans at special conditions	Yes	Yes	No
Feed-in tariffs	Yes	Yes	No
Green certificates	No	No	Yes
Indirect support (carbon tax)	Yes	No	Yes
Additional support for small-scale facilities	Yes	Yes	No
Incentives for use of manure as feedstock	Yes	Yes	Yes
Gate-fee for waste handling	No	Yes	No
Incentives for use of energy crops	Yes	No	No
Knowledge-Oriented Support			
Support through information actions	Yes	Yes	Yes
Biogas as part of rural development strategies	Yes	Yes	Yes
Biogas as part of manure handling strategies	Yes	Yes	Yes
Additional Support Measures			
Priority access to national electric grid	Yes	Yes	No
Priority access to national gas grid	Yes	No	No
Preferential conditions for gas-fuelled cars	No	No	Yes
Extensive district heating networks	No	No	Yes

On the biogas utilization side, community-based approaches to renewable energy adoption have the potential of increasing opportunities and reducing risk for all actors involved in the local energy supply chain. Such approaches can increase actual availability and usability of feedstocks, and may be more successful than central, politically-imposed initiatives based on financial incentives of limited scope and duration. To fully exploit REPs advantages (*i.e.*, residual heat generation) incentives to build or enlarge district heating consortia could be of great importance for the logistic of biogas projects. Such networks are extensively present in some countries (e.g., Sweden), less in others (e.g., Germany), and practically non-existent in a few (e.g., Spain, Italy). Aspects related to gas transport networks development are being discussed at the EU level, such as the possibility of common specifications and standards for biomethane gas quality, installations, and equipment for both gas producers and consumers connected to local grids [38].

Non-Technological Barriers to Biogas Use

When discussing the promotion and development of the biogas sector it is of the utmost importance to take existing non-technological *barriers* (*i.e.*, unrelated to technological processes but limiting the subsequent diffusion of the product's use) into account. The term barrier is a metaphor to indicate constraining factors that may affect the implementation of REPs, and is normally used as an effective way to draw attention to the challenges facing these systems. There are actually no absolute barriers to achieving EU REP potentials, but rather factors affecting their implementation stage at various levels. These can be summarily divided into economic, administrative, and market-related barriers [39]. Example of the first category are: need of large investment, lack of long-term perspective, low profitability (e.g., in sales of biogas or electricity), limited final uses for heat produced, limited investment resources (e.g., due to financial crisis), costs of grid connection, logistic difficulties for feedstock procurement. Financing is frequently mentioned as a problem for the implementation of biogas projects in many countries. Project profitability may suffer from lack of long-term perspective, save for specific situations, such as small-scale biogas facilities in Germany, where the general situation is such that a farmer could set up his own small biogas plant and see it quickly become profitable much like, for instance, photovoltaic (PV) in other countries [31]. In some countries, the connection to the electricity grid (connections of small producers to a gas main is virtually non-existent) may be rendered difficult by the grid operator, who could allow connection only at distant sites, entailing such a high cost that an entire project becomes unprofitable. Among administrative barriers are: overwhelming bureaucracy (including difficulties in obtaining permissions), instability of policies and discontinuity of support measures, and lack of public acceptance of the technology. In some countries, the process of application and authorization is rather convoluted, and may need up to two years or more to complete. This may lead investors to lose interest, in view of the significant upfront expenses and faraway returns, and slow down the development of the entire sector, locally.

As mentioned, stability of policies and tariffs is of great importance for the development of new technologies. In Spain, as well as Italy, unexpected changes of feed-in tariffs and incentives lead to a decrease of private investments, and unwillingness of banks to grant new loans. Market-related barriers include: immature market, costly upgrading of infrastructure and end-of-use facilities, lack of transport infrastructure and storage capacity, seasonal variability of feedstock supply implying volatile buying costs, sparse distribution network (e.g., few filling stations for automotive uses), and cost competition with natural gas. Public opinion of local biogas production can be rather negative in many countries (with the possible exception of Switzerland), as it is associated with handling of waste, possible air pollution, bad smells, and increased road traffic for feedstock supply. The importance of public opinion should not be underestimated, as organized public opposition may delay implementation of planned projects for years [40,41].

A multi-national study on the identification and analysis of barriers for bioenergy in the EU, recently completed, showed economic conditions, know-how and institutional capacity, and supply chain co-ordination to be the key barriers obstructing the expansion of bioenergy [39]. The study highlighted some supply-chain barriers, previously undetected, such as the limited flexibility and uncertainty of short-term economic gains associated with energy crops by farmers, and their limited experience (know-how) with these crops. In order to make farmers' entrepreneurial risk acceptable, contracts between the latter and energy companies should involve a third-party guarantor (e.g., local governments) to create a climate of confidence and promote energy crop diffusion. In some countries (e.g., Poland) there exist, however, practical disincentives that discourage farmers to invest and harvest energy crops [39].

When it comes to establishing bioenergy systems, specific know-how and institutional capacity is needed at all levels: lack of project terms understanding by bank staff (to negotiate a loan/lease) could be a barrier, as well as a lack of experienced operational and maintenance staff. Often, there is a lack of capacity for proper technical training of professional staff in this field.

Across MSs, different conditions lead to different experiences with key barriers across both at the national and the local level. The context for bioenergy systems is largely defined by their location and the main actors involved in each project. Overcoming non-technological barriers for bioenergy projects implies dealing with locally varying conditions, and understanding the importance and relevance of the local context. In a nutshell, each bioenergy project is different. Table 3 summarizes some recommendations to overcome non-technological barriers to biogas use in EU according to what discussed in this section.

Table 3. Summary of recommendations to overcome non-technological barriers to biogas use in EU.

Barrier Type	Description	Recommendations
Economic	Large investment needed/limited resources	Investment grant schemes by State or financial institutions. Low interest grant availability. Financial/taxation incentives of community entrepreneurship (*i.e.*, local cooperatives).
	Lack of long-term perspective	Consistency of engagement rules over time. Relative certainty about investment returns. Stability over time of legislation concerning the entire energy supply chain.
	Low profitability (of energy market price)	Differential taxation of renewable and non-renewable sources (*i.e.*, carbon tax) should be used to leverage energy prices when market is volatile and fossil fuels become excessively cheap.
	Cost of grid connections	Binding regulations for both electric and gas grid connections. Rules to avoid dominating positions of energy providers.
	Costs of feedstock supply	Agricultural and environmental protection policies should contain provisions to encourage consistent production of non-food energy crops. Proper preliminary analysis of feedstock supply chain. Contracts between farmers and energy companies should involve third-party independent guarantor. Under local cooperative projects, suppliers of feedstock and energy producers are the same subject, assuring consistent vision.
Administrative	Overwhelming bureaucracy	Rules to obtain permissions should be clear and straightforward. Application processes should be streamlined, with relative certainty about approval times. Situations where minority stakeholders can stall projects without good reason for long periods should be avoided.
	Policy and support measures instability	Should be avoided in all cases. May condition motivation of investors, and willingness of banks to provide loans.
	Public acceptance issues	Should be dealt with by professionals since project inception. Public must be treated fairly by private investors in order to accept new projects. Information about each project should be made available to all stakeholders to reach an informed opinion. Non-acceptance is uncommon in case of local cooperative initiatives.
	Know-how and institutional capacity	Public administration personnel, bank officials dealing with these projects should receive specialized, ad hoc training to help reach motivated decisions. Expertise in energy supply-chain coordination should be developed. State/local governments should encourage the creation of bioenergy communities (as in Germany) for the development of these projects.

Table 3. *Cont.*

Barrier Type	Description	Recommendations
Market-related	Immature market.Expensive infrastructural and end-of-use facilities upgrades	Adoption of Strategic Niche Management protection mechanisms by States/EU in order to allow solid establishment on the market. Adoption of State/local infrastructural upgrade programs.
	Lack of transportation/storage capacity	Feedstock transportation and storage, and lack of energy storage may cause disruptions in the renewable energy supply-chain. These aspects should be carefully evaluated during the planning phase. Biogas upgrade to biomethane should be considered if large-scale storage is necessary.
	Seasonal variation of feedstock supply	Proper preliminary analysis of feedstock supply chain. It is usually possible to achieve uninterrupted biomass supply by proper rotation of locally available feedstocks. Agreements between suppliers and energy producers should address this potential problem.
	Sparse distribution networks	Availability of a redundant distribution network for the energy generated is essential, if not all the consumption is onsite. Distribution should satisfy all forms of produced energy (electric, heat, gas) in order to make the project maximally efficient.
	Lack of energy users	Since in most cases various forms of energy are produced, available users should be present for each one. Often, incentives are focused solely on the production of one form of energy (e.g., electric) and neglect co-production of other forms (e.g., thermal) that ends up wasted for lack of local demand. Incentive structures should consider energy production maximization according to local demand, fostering facility building where they are most necessary, and can substitute the greatest amount of fossil energy.
	Price competition with natural gas	Natural gas is subject to extended price oscillations, following actual demand and geo-political events. The cost of renewable energy production is more or less constant (amortization of biogas plants) with smaller variations due to feedstock availability. The latter can be stabilized with proper agreements between suppliers and energy producers. Differential taxation schemes between renewable and non-renewable energy should be implemented in order to render the former always advantageous compared to the latter.

5. Institutional and Regulatory Support for Biogas Diffusion

Public policies have played an important role in stimulating the spread of biogas plants, however, in order for the development of the biogas sector to continue, persistent driving forces are necessary, either through EU directives, local legislation, or from private initiative. As production conditions vary substantially in different Member States and within their regions, national support initiatives adapted to local conditions would ideally be needed to complement and integrate more general EU measures. Entrepreneurship at a local level by groups of people interested in a more sustainable energy system should be encouraged by different, new means of support.

Currently, incentive structures play an important role in determining plants size, as well as mode of biogas use. Since biogas is "plugged" into a regulatory system for renewable energies (together with solar, hydro, and geothermal) in which priority is given to electricity generation, this has resulted in a functional orientation toward maximizing electricity production within biogas facilities. Until now, for example, heat-only production and injection into the gas grid are utilization possibilities that have been largely ignored by incentive schemes. Biogas (biomethane) is also mostly excluded (incentive-wise) from sustainable transport policies.

Biogas can have purposes other than the production of electricity alone, like district heating and transportation, in which its use would be more efficient and sustainable in terms of energy and environmental benefits. Under-utilization of these plants' thermal energy generates additional environmental inefficiency: since producers have no incentive to use the heat produced (*i.e.*, from cooling of engines/turbines for electricity production) beyond the amount locally needed, nor it is usually convenient to create special infrastructure for its exploitation, excess is released in the atmosphere. In view of these considerations, an overall reorganization of incentives is generally needed, taking into account the promotion of socio-territorial integration, rewarding the overall recovery of energy and of all other by-products from each project, as well as diversification of biogas' final uses [42].

A solution could lie in promoting renewable energy projects in new organizational forms, such as collective 'community energy' projects. Locally, collectively owned energy production facilities have become a growing issue over the past two or three decades, since such organizational forms open up financial opportunities, help create a wider basis of support and make sense not just economically and logistically, but also in terms of mobilizing existing resources. In Denmark, for example, collectively organized renewable energy production sites exist for wind power and agricultural biogas [37]. In Germany, local solar power (photovoltaic) community initiatives have played a crucial role in market formation for that technology [43]. In South Tyrol (Italy) collectively organized, largely (85%–90%) manure-based biogas installations have been collectively developed by nearly 400 farmers organized on a cooperative basis for the local REP development [44]. A similar experience was implemented by the local agricultural cooperative of the village of Feldheim (Germany) in 2008. A biogas plant generating 4 GWh of electricity a year is operated with an annual biomass input is 8600 m^3 of manure, 8700 tons of maize and 190 tons of wholegrain cereal, produced and supplied by the agricultural cooperative itself [45]. Still in Germany, the town of Jühnde (Lower Saxony) supported the creation of a cooperative society (with 70% resident participation), leading to an investment of 5 Million Euro to build an "Energy Village" with a co-digestion biogas plant rated 712 kW, a heating system rated 550 kW, and a hot water grid with an extension of 5.5 Km. The electricity produced since 2005 is twice that locally consumed, while the rest is sold to the national grid. It is estimated that each household in Jühnde saves about 1000 €/year in energy expenditures, and avoids GHG emissions for 25 t CO_2/y. As of today, there are at least 17 other similar cooperative "bioenergy communities" operating in Germany [46].

Empirical analysis of such situations shows that specific institutional features of the communities involved (community spirit, culturally established cooperative tradition, value of locality, and common sense of responsibility in terms of local environmental protection) have shaped the emergence and constitution of these collectively run REPs. Although not immediately replicable everywhere, community energy can nevertheless be considered a promising way of organizing projects to implement renewable energy technologies, as well as a strategy for making energy generation and consumption more local, and thus more sustainable, transforming predominantly centralized energy supply systems into more decentralized ones.

6. Discussion and Conclusions

Biogas production and use is one of the pillars of the EU strategy for fossil fuels replacement by renewable energies. A very large untapped potential for biogas production still lies in the digestion of manure, agricultural residues, and alternative (non-food) energy crops, which are currently started being investigated for this purpose. Vast energy recovery and substantial GHG-emissions savings may be attained with co-digestion of manure and energy-rich crops, while production processes improvement is constantly investigated. At the moment, however, digestion of biomasses and biogas production are more than often regarded mainly as a means to obtain rural development. Energy production, pushed by economic incentives, is mainly geared toward electric energy production, with limitations linked to network accessibility and feed-in prices. Alternative uses of biogas-produced energy are hardly incentivized, and mostly ignored. A strategy for further development of biogas production would require well-rounded, long term incentives for a true SNM strategy promoting overall energy recovery in all its possible forms (heat, especially for districts, grid injection of biomethane, transportation-related uses) that may even be more efficient than electric energy production. This would allow to both optimize onsite uses and extend the benefits of REPs to more distant areas. Beneficial uses of digestate, as fertilizer or as a source of raw materials, should be further investigated and promoted.

Non-technological barriers should be analyzed and addressed by appropriate actions, on the economic, administrative, and market sides. Regardless of existing investment subsidies and preferential loans, the substantial initial investment needed for a biogas project may still act as a significant obstacle, which may be overcome by setting up financial schemes at the local scale, minimizing other barriers and assuring fast execution and early profitability of projects. Biogas projects cannot be handled in a fast-through, rubber-stamp manner. There is no single general way of planning and implementing, and each case needs to be addressed and planned in a way suitable to local conditions. Public opposition to the creation of new biogas plants is rather common: promotion of REPs under new organizational forms, such as collective "community energy" projects, where local communities share concerns for the environment and sustainable development, balancing local costs and benefits, may be a possible solution. Community-based diffusion approaches may have the potential of increasing opportunities and reducing risk for all the actors involved in the energy supply chain, and may increase actual availability and usability of base feedstock. Where implemented, this appeared to be more successful than politically-imposed initiatives based solely on financial incentives of limited scope and duration. Proper education and active, timely communication to local residents may, over time, win even the diffidence of NIMBY*ers*.

As the greatest potential of biomass digestion is on the country-side, due to feedstock availability logistic, a standing question is whether a large amount of smaller plants is desirable or if the focus should be on fewer, large-scale plants. It is possible that introduction of small-scale technology would not face problems of public acceptance as severe as large scale projects. Making a comparison to the successful Danish implementation of wind farms, it could be concluded that acceptance and successful development of new technology is facilitated by starting on a smaller scale. If more effort is put into avoiding small-scale projects problems, these positive experience may encourage subsequent implementation of large-scale ones. Scientific and technical authoritativeness of the technology, and trust between local people and groups promoting the projects are both part of the conditions (procedural justice) that can help projects work.

Issues like monoculture of energy crops, stressing local agricultural economic systems, odors and traffic induced by transportation of substrates and digestates may be solved though intelligent solutions, such as well-planned crop rotation, that may also help reduce biomass supply volatility, or land-lease by small farmers to energy companies which can then involve firms specializing in energy crops for their management. Proper gaseous effluents control and transportation of material mostly through pipelines could also be applied. Distributive justice aspects shall be fairly addressed, so that all stakeholders will appreciate equitable local spread of project benefits.

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