The Phantom Menace:
Bridging the Regulatory Gap for Sustainable Biogas

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Abstract

Biogas is a key component of the energy system of the future. Once upgraded to biomethane, it has a similar chemical composition to natural gas, thus offering a promising alternative to fossil fuels. For instance, it can be injected into the natural gas grid or power gas-fueled vehicles, thus contributing to the decarbonization of the transport sector. However, biogas production is not always environmentally sustainable. On one hand, biogas production from waste (e.g. manure or agricultural residues) represents an effective way to promote virtuous circles of resource use and re-use. On the other hand, the production of biogas from energy crops poses serious sustainability challenges, due to the negative impacts on biodiversity and the possible competition with food and feed crops. Similar risks are taken into account in the policy framework of the European Union (EU), which, following the adoption of the new Renewable Energy Directive (RED 2018), provides specific sustainability criteria for biogas production. Outside the EU, few other jurisdictions specifically address sustainability challenges related to biogas production. Adopting an interdisciplinary approach, in the first part of this paper we conduct an LCA analysis to assess the regionalized impact of biogas production from different feedstocks. In the second part of the paper, we analyze the essential elements of the EU sustainability criteria and, taking stock of the results of the LCA analysis, we propose a threefold set of policy recommendations to increasingly promote biogas sustainability, with a specific focus on developing countries.
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Alessandro Monti, Daniel Oderinde & Maria Polugodina

1. Introduction

The melting of glaciers, sea level rise and extreme weather events are no longer mere scientific predictions of some distant future, but an everyday reality in many parts of the world. The latest report published by the Intergovernmental Panel on Climate Change (IPCC, 2018) pictured the daunting consequences of global warming exceeding 1.5 °C above the pre-industrial levels, the ambitious target set under the Paris Agreement (UNFCCC, 2015). To tackle such unprecedented challenges, far-reaching policy reforms in numerous economic sectors are needed. Several of the 17 Sustainable Development Goals (SDGs), approved in 2015 by the UN General Assembly (United Nations, 2015), set the course for such reform efforts.

The energy sector, in particular, is responsible for the largest share of global greenhouse gas (GHG) emissions (IEA, 2019a), and SDG 7 (“affordable and clean energy”) mandates a transition away from fossil fuels. Hence, renewable energy (RE), i.e. energy produced from renewable sources in a sustainable manner (IRENA, 2009), has a central role to play for a sustainable development of the energy system. This paper focuses on one specific category of renewable energies, namely biofuels, due to their large untapped potential to be deployed in the transport sector. Within this category, the focus is further restricted to gaseous biofuels, also known as biogas. When upgraded to biomethane, biogas has a significant potential to be directly applied to the transport sector, also powering heavy-duty vehicles (Wilken et al., 2017). Moreover, biogas can be produced from a wide variety of feedstock, including waste, therefore having high potential as a springboard for the circular economy.

However, biogas, not unlike other biofuels, faces specific sustainability challenges. The production of biogas from agricultural feedstock, through the use of energy crops, represents a potential threat to agricultural land and may lead to phenomena such as the spreading of “Maiswüsten”, i.e. “maize deserts” exclusively dedicated to the cultivation of maize for biogas production. Hence, this study aims to take a closer look at the biogas value chain, to foster an enhanced understanding of biogas sustainability and promote scientifically-sound policies. With reference to the SDGs, our approach will particularly highlight possible options to foster synergies between SDG 7 (“affordable and clean energy”) and SDG 13 (“climate action”) and SDG 12 (“responsible consumption and production”).

The challenges of biogas sustainability have already been addressed in numerous studies. A common approach is the development of a life-cycle-assessment (LCA), to quantify the impacts of biogas production for different plant configurations (for a recent review of LCA studies on biogas, see Hijazi et al. (2016)). Among the most recent studies, Omar (2017) and Lyng & Brekke (2019) show that biogas from waste is the more sustainable than biogas from agricultural crops.
and other carbon intensive sources. The reason is that the production of biogas from agricultural cultivation requires several steps including farmland preparation, fertilization, machineries, crop harvest, etc. Lyng & Brekke (2019) also observe that the choice of the crop has an impact on GHG emissions, and that perennial crops are more sustainable than the annual ones. A common feature of these studies is that they usually take a selection of existing biogas plants in a certain country and compare feedstocks, plant sizes or technologies to each other. What seems missing, however, is a broader outlook transcending those studies. Does the same plant have an equal impact everywhere in the world? Or is it dependent on where the plant is located? What is the geographical distribution of the impact?

The promotion of biogas sustainability has numerous policy implications. In this sense, one of the most advanced regulatory frameworks can be found in the European Union, which, since the adoption of the first Renewable Energy Directive (RED 2009), has included sustainability criteria for biofuels. Such criteria, were originally formulated with regard to liquid biofuels. Yet, in 2018 an updated version of the Renewable Energy Directive was adopted (RED 2018), which extends the applicability of numerous sustainability criteria also to biogas production. Outlining the key features of the EU legal framework will serve as a useful reference to propose strategies for the development of sustainable biogas policies also in extra-EU jurisdictions.

Adopting an interdisciplinary approach, which covers both technical and legal aspects of biogas production, our paper investigates the role of sustainability in biofuels and biogas policies, addressing the following research question: How can the production of sustainable biogas be promoted through scientifically sound policies?

This main research question is further articulated in the following sub-research questions:

- What is the environmental impact of biogas production from different plant configurations?
- How does the environmental impact of biogas production differ spatially?
- Which policies and regulations address sustainability concerns?
- How can existing policies be improved?

Our paper answers these interrogatives by adopting an interdisciplinary approach and bridging the gaps between studies in environmental and legal sciences. The analysis is divided into the following two steps.

First, we employ the LCA approach to calculate the regionalized impact of biogas production from different feedstocks. Differently to other LCA studies, we do not focus on the overall effect of an existing plant in a specific country. Instead, we take into account that regional differences e.g. in climate can influence the sustainability of the same type of biogas depending on the plant location. A prominent example here is variation in the yields of the energy crops. In places where the soil is less productive, larger harvest areas or better fertilization are needed to produce the same amount of biogas. Apart from that, the production of fertilizers and plant parts is often not located in the same region as the biogas plant itself. Therefore, we draw on Geographic Information System (GIS) data to support our analysis and perform a regionalized LCA for a hypothetical plant, which has the same technical characteristics in every location we consider.

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1 For verbal simplicity, we will often refer to biogas from different feedstocks as “types” of biogas throughout the paper.
Second, we review the existing policies regarding biofuels and biogas sustainability. Moving from a review of the EU sustainability criteria, as updated under the RED 2018, we propose a number of policy recommendations to foster sustainable biofuels and biogas policies in extra-EU countries, with a special focus on developing countries.

The remainder of the paper is structured as follows. In Section 2, we provide a brief overview of the production, applications and sustainability concerns of biogas. Section 3 illustrates our research approach. Section 4 presents the results of the LCA analysis. Section 5 addresses the EU legal framework for biofuels and biogas. Section 6 analyses the global relevance of the EU sustainability criteria and provides some policy recommendations for the promotion of sustainable biogas. Section 7 concludes the paper.

2. Biogas and biomethane: an overview

2.1. Biogas production: sources, processes, applications

Biogas is a mixture of gases, with high share of methane (usually 50-70%), produced through decomposition of organic matter (biomass / feedstock). Biomethane is in turn a result of biogas upgrading, whereby other gases are removed from biogas and methane share reaches over 90%. In a broader perspective, biogas is one of a number of biofuels. Biofuels are based on plant biomass that can be burned to produce energy, in which they are similar to fossil fuels (Guo et al., 2015). They, however, have faster recovery rates, which makes them considered as renewable energy (ibid.). Biofuels can be solid (e.g. firewood), liquid (bioethanol, biodiesel, etc.) or gaseous (biogas) (Creutzig et al., 2015; Guo et al., 2015). Importantly, they can be utilized in different areas, such as transport, cooking as well as heat and electricity production (Creutzig et al., 2015).

Among these fuels, biogas stands out as a relatively new fuel, with high potential but relatively underdeveloped today. While Guo et al. (2015) predicted that biogas may replace up to 25% of current natural gas demand, by 2016 biogas production was still negligible, comprising only one-fifth of all bioenergy globally, which in turn covered only 8% of all RE production (IRENA, 2018). Yet, biogas represents a number of advantages, relative to other biofuels: Unlike other biofuels (e.g. biodiesel or bioethanol), biogas production can use a large variety of feedstocks, including special energy crops (maize, lay crops, sweet potato, straw, etc.), agricultural waste (plant residues and animal manure) and municipal waste (Guo et al., 2015). This can contribute to an additional area of waste management both in rural and in urban areas. It also diminishes the need for growing specific energy crops, which put under doubt the social and environmental sustainability of other biofuels (Guo et al., 2015; Röder, 2016; de Andrade, 2016; Achinas et al., 2017).

The widely used and commercially most successful technology for biogas production today is anaerobic digestion (AD) (Koornneef et al., 2013). In this process, a certain group of bacteria transform the biomass into biogas and digestate (biofertilizer) in absence of oxygen\(^2\). Compared to the refined natural gas delivered to the end user, biogas has a lower share of methane but a higher share of carbon dioxide as well as other components such as water vapor, hydrogen, sulphide and ammonia (Muzenda, 2014; Zhou et al., 2017). Therefore, in some cases (e.g. to be

\(^2\) For the description of the technical process see e.g. Achinas et al. (2017) and Muzenda (2014)
used as a vehicle fuel), it has to be purified of contaminants (especially CO$_2$), that means, upgraded to *biomethane*\(^3\).

The main advantage of biogas is that it is easily stored for longer periods of time, so it can be treated as a stock energy, just like the fossil fuels. This important feature differentiates if from electricity from hydro-, solar and wind power, which are the largest renewable energy sources today (IRENA, 2018). In addition, both the main product of biogas production (the biogas itself) and the by-product (the digestate) can be put to efficient use (Wilken et al., 2017). Namely, the digestate can be used as an organic fertilizer, while biogas itself has three main applications: heat generation, power generation and transport fuel. Biogas is primarily used for heat or power generation, often also in combined heat and power (CHP) units (ibid.). Upgraded to biomethane, it has almost the same chemical composition as natural gas. It can, therefore, be used in all types of gas-fueled vehicles and, thus, make use of already existing fleets and commercially available technologies (Svenssson, 2013). Where a grid exists, biomethane can be freely intermixed with natural gas to be easily transported over large distances. Where no grid is available, the biomethane can be compressed or liquefied and transported very efficiently by road (Roggenkamp et al., 2018; Svenssson, 2013). This also makes it stand out in comparison with hydrogen, which is still costly to produce and transport and is debated in terms of its GHG savings (Ali et al., 2016).

Another application of biogas, which has been mentioned above, lies in the possibility to produce it from agricultural residues and municipal waste, thus offering a viable alternative to composting or landfilling the waste and contributing to sustainable waste management.

### 2.2. Biogas as a sustainable energy source

The production of biogas from agricultural and municipal waste is one of the trending and promising environmentally friendly technologies in the world today. This is because biogas production is driven by energy sustainable processes that contribute relatively less to climate change, compared to natural gas production from fossil fuels (Jíří et al., 2016). With a rise in biogas energy production from 0.28 exajoules to 1.33 exajoules between 2000 and 2017 (Wang, 2019), the global biogas production is projected to be worth 110 billion US dollars by 2025, with a compound annual growth rate of 7% (Global Market Insights, 2019).

Considering the growing market of biogas globally, special care has to be taken in ensuring that the production and consumption of biogas are in line with and do not negatively affect the three pillars of sustainability, namely the economy, environment and society. These three pillars are relevant and applicable in accessing the sustainability of biogas as a renewable energy source (Purvis et al., 2018). Based on the focus of the EU sustainability criteria, the major aspect analyzed in this paper is the *environmental* sustainability.

This paper addresses the factors related to biogas environmental sustainability, analyzing the life cycle of biogas production in terms of GHG reductions against the fossil fuels comparators, as well as in terms of the feedstock used to produce biogas. The use of municipal and agricultural waste, in particular, appears as a viable option to solve environmental issues through the creation of a suitable end of life for waste and the reduction of the amount of waste remaining in the landfill.

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\(^3\) For a comprehensive overview of upgrading techniques, see e.g. Wilken et al. (2017)
sites (Jonas et al., 2017). The problem of GHG emissions at landfills not equipped with gas capture is thereby reduced, and, as a result, air pollution is diminished. Because the landfills are usually close to the cities, biogas plants are often established close to them and, by this, the distribution of energy becomes simpler and more efficient, compared to the fossil energy (Jacopo et al., 2013).

Conducting a Life Cycle Sustainability Assessment (LCSA), which also includes a Life Cycle Assessment (LCA), represents a promising tool for evaluating sustainable production and consumption. This tool is also considered as the best approach to analyzing the environmental, social and economic sustainability of production processes (Hannouf & Assefa, 2019). To illustrate the sustainability of biogas production against carbon intensive energy sources, we first conduct an LCA and compare the environmental impacts of the production of biogas against carbon intensive energy sources. In obtaining quantitative results, the environmental impacts due to the generation of 1MJ of energy were calculated for biogas from waste and diesel production. Diesel was chosen as a fossil fuel comparator due to its high level of industrial application. The same amount of energy yield was chosen, so that the environmental impacts are directly comparable.

Each production process impacts the environment, in a very general sense, along a number of directions. For the LCA analysis, the EU has recommended a set of Life Cycle Impact Assessment methods (JRC, 2012). There, major impact categories for any production chain include: climate change (in CO₂-equivalent), ecosystem quality, human health and resource use. Each of them is further detailed, e.g. the climate change may be induced by the use of fossil fuels, land use and land use change (LULUC) or through biogenic impact (ibid.). With a focus on the three major impact categories in the EU sustainability criteria – climate change, land use change and fossils as a resource – the results of the first brief analysis are provided in Figure 1. The figure shows that the production of biogas can achieve an 86% reduction of GHG against the production of diesel. Regarding the reduction of land use, an 84% reduction can be achieved, and there is no significant impact of biogas production on fossil fuel consumption, when compared to diesel production.

![Comparison of impact categories](image)

*Figure 1: LCA environmental footprint results for biogas from waste versus diesel. tons per hectare.*
It must be noted that this brief comparison shows the “best case” scenario, since – as mentioned before – biogas from waste is the most sustainable biogas type (Omar, 2017). The sustainability of biogas from energy crops is, on the contrary, contestable, even when judging on the mere basis of the overall impact (Guo et al., 2015; Röder, 2016; de Andrade, 2016; Achinas et al., 2017). On top of that, the environmental impact of biogas generation from energy crops can potentially vary in different regions of the world due to varying crop yields. Therefore, the rest of the paper will specifically focus on the production of biogas from energy crops.

3. Research design

We perform our analysis in two main steps. First, we investigate the environmental sustainability of biogas from a regionalized perspective. Second, we review how existing policies tackle the sustainability issues of biogas production. We then combine the results of the two analyses to suggest tailored policy recommendations aimed at enhancing biogas sustainability outside the EU, and particularly in developing countries.

For our analysis of the environmental sustainability of biogas, we assess the environmental impact of its production – to which we will also refer to as footprint – along several impact categories. We use the Life Cycle Assessment (LCA) approach, and the impact categories correspond to those defined by the EU (JRC, 2012). They will be specifically referred to below, in connection with the specific software we use. Unlike other LCA studies, we are looking at how the overall footprint is distributed across the world, and how this distribution changes if we move our hypothetical plant to different locations. Just like in the case of goods production, one might expect GHG emissions in biofuels production or environmental effects of crop cultivation to fall into international responsibility (for goods, see Pan et al. (2008) for an example of China’s role in international trade and GHG emissions). At the same time, as will be shown later, only a few countries deal with biogas sustainability within their territories, let alone from a cross-border perspective. To grasp the relevance and effects of this perspective, we perform a regionalized LCA.

We split the LCA analysis into further two steps. We first compare the regional impacts for an arbitrary (“global”) biogas plant location to examine if the patterns differ between the feedstocks. As it is primarily biogas from energy crops, which raises sustainability questions in the literature and in the public (Kline et al., 2016), we only look at this group of feedstocks. The two most often analyzed energy crops are maize and sugar beet (see Hijazi et al., 2016). Thus, given the scope of our paper, we limit ourselves to these two feedstocks.

We then focus specifically on several plant locations to investigate how the location changes the pattern for the specific feedstock. For that, we analyze four plant locations in four different parts of the world: Brazil, as the major biogas producer in the Latin America and among the developing countries (due to the large country size, we focused specifically on the state of Paraná, where UNIDO-GEF projects for biogas promotion have been active since 20154), China and Germany, as the major biogas producers in Asia and Europe respectively, and Nigeria, as the emerging biogas producer and the seat of the African Biorenewable Association. These countries represent very different stages of economic development, and one of the questions we want to test with our LCA

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4 See e.g. the “Biogas Applications for the Brazilian Agro-industry” project at www.thegef.org/project/biogas-applications-brazilian-agro-industry (accessed 27 October 2019).
analysis is if the sustainability concerns are equally relevant for both developed and developing countries.

We use the OpenLCA software and the ecoinvent database to perform the analysis. The software is capable of evaluating environmental impacts and other relevant environmental and economic aspects for each part of the value chain, from the extraction of material, through transport and production, to the end-use. The OpenLCA provides results along the impact categories, as recommended by JRC (2012). A brief overview of these categories is provided in Table A1 in Appendix 1.

For agricultural biogas, the ecoinvent database only contains the processes for biogas plant construction and production of biogas from animal manure. For energy crops, we have to create a new process based on this existing one. To analyze the effects of biogas production from maize and sugar beet, the process for manure was taken as a basis. Specifically, the inputs of agricultural plant construction and of energy and heat to operate the digester were taken from that example.

The input of feedstock was replaced with the respective energy crop as follows: The amount of feedstock needed for biogas production was calculated using the potential biogas yield from the literature: 0.66 m$^3$/kg of total solids for maize as in Hutňan (2016) and 0.685 m$^3$/kg of total solids for sugar beet as an average of the findings of Starke & Hoffmann (2014). The share of total solids in the fresh crops for the respective feedstocks was taken from Kreuger et al. (2011), who provide a comprehensive overview on a number of crops. To specifically investigate potential regional differences arising from varying soil productivity, we added two input processes, which were not relevant for biogas from manure. Firstly, we account for the amount of land needed to grow the energy crop, based on the regional yields provided as GIS data by Monfreda et al. (2008) in the EarthStat project. The spatial distribution of yields is illustrated in Figures A1 and A2 in Appendix 2 for maize and sugar beet respectively. Secondly, we add the process for transportation of the feedstock to the plant. For manure feedstocks, it is typically assumed that manure is collected in a barn (Lusk, 1998; Homan, 2012), so the transportation distance is negligible, provided the biogas plant is constructed not far from the barn. For energy crops, the same cannot be the case: the crops have to be delivered from the whole cultivation area, and this distance needs to be accounted for. To do so, we assumed the plant to be located within a square field, where the crop is grown, and used the average distance within a square as the transportation distance, choosing a lorry as means of transport. The estimation of the environmental impact was then done using the ILCD 2.0 2018 midpoint method. The amount of biogas produced is normalized to 100 m$^3$ for the sake of comparability.

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5 OpenLCA is a professional LCA and footprint software that has a variety of features and many available databases. An important advantage against other professional LCA software is that openLCA is an open access software. It is also endorsed by the US Environmental Protection Agency (cfpub.epa.gov/si/index.cfm). The ecoinvent database is an extensive and comprehensive collection of datasets on life cycle inventory, including a large number of products, production processes and value chains (see https://www.ecoinvent.org/ for more information on the database).

6 The results of a regionalized LCA reflect the contribution of different regions to the overall impact, i.e. the percentage share of the respective region. Therefore, scaling the amount of biogas up or down will not change the results. We experimented with 1 m$^3$, 100 m$^3$ and 100000 m$^3$ of biogas, and the result was qualitatively always the same.
4. Regional impacts of biogas production

In this section, we present the results of the regionalized LCA. We start by briefly comparing the overall impacts of biogas production from maize and sugar beet. After that, we focus on the results in a regional perspective, first with unknown plant location and then for four different plant locations.

Regarding the overall impact of biogas production from maize and sugar beet along the impact categories listed in Table A1, it should be noted that maize has a much larger impact than sugar beet on all categories. The comparison is illustrated in Figures A3-A6 in Appendix 3, and this result is in line with the findings outlined by Hijazi et al. (2016). However, the regional impacts of the two feedstocks show quite some differentiation.

The first finding is that the regional distribution of the impacts differs substantially between the two agricultural feedstocks. For the sake of brevity, we only provide results for three impacts, which are also addressed in the EU sustainability criteria: climate change due to land use and land use change, use of fossils as a resource, and use of land as a resource. The comparison is illustrated in Figures A7-A9 in Appendix 4. The maps show relative contributions of the respective regions to the overall impact: the warmer the color on the map, the larger the region’s contribution.

In terms of land use and the LULUC-induced climate change (Figures A7-A8), the regional variation follows quite closely the world industrialization patterns, on the one hand, and the agricultural productivity, on the other. In case of maize, the impact is most prominent in Argentina both for land use and LULUC-induced climate change. This is not surprising, as on the one hand, Argentina is among the top five maize producers across world, while, on the other hand, Argentinian agriculture is responsible for 90% of the country’s forest loss (Antón et al., 2019). The latter is translated into the LULUC-induced climate change. In the case of sugar beet, the LULUC-induced climate change is prominent in Brazil, however there is no overlap with land use as a resource. This suggests that the effect is not due to sugar beet production, which is also in line with Figure A2 in Appendix 2. A closer investigation reveals that additional electricity production for agriculture and the plant would have the highest LULUC-related environmental costs in Brazil, where the majority of electricity is supplied by hydropower and water reservoirs created for that pose a number of environmental challenges (von Sperling, 2012).

With regard to the use of fossil fuels (Figure A9), the major impacts are, as could be expected, in the fuel- and mineral-exporting countries. The impact comes, on the one hand, from the energy for plant construction, operation and from the fuel used for feedstock transportation. On the other hand, it also reflects the resources for fertilizer production, which is quite important in crop agriculture.

Turning to different plant locations, the second important finding is that, while certain impacts are connected to plant location, others are always attributed to the same regions. The results of the comparison for sugar beet are illustrated in Figures A10-A11 in Appendix 5. The results for maize

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7 The drawback of the OpenLCA software is that it does not provide an exact scale for the regionalized results. The illustrative maps should, therefore, be considered as a qualitative, not quantitative reference.

8 Based on FAO data: www.fao.org/faostat/en/#data/QC (accessed 8 December 2019)
are presented in Figures A12-A13 in Appendix 6. Again, the higher contribution of a region to the overall impact is marked with warmer colors. For sugar beet, particularly the effects related to growing the energy crops “move” together with the plants (see the impact on the land use in Figure A10). In the case of maize, Argentina seems to be one of the source countries for the feedstock for all four plant locations. Unlike other major maize (corn) producers, not only is Argentina the third largest exporter of corn, but also corn figures as the second largest category of Argentinian exports. At the same time, part of the impact is still located in the country of the plant location. Another interesting observation, in the cases of both maize and sugar beet, is that the more developed the country, the lower the impact share. This also overlaps with the distribution of yields in Figures A1-A2 in Appendix 2.

Turning to other resources, the picture is similar to that with the undefined plant location. Both for maize and sugar beet, especially the use of resources related to fertilizers, plant construction and transportation (minerals and metals) is associated with the same regions, independent of where the plant is located. In other words, fossil energy, construction materials and fertilizers often do not come from the same country they are used in. This raises the question, in how much the impact created by this demand is taken into account by the policy-makers when promoting biogas or setting the criteria for determining whether to call biogas a sustainable renewable energy.

To sum these results up, there are several observations relevant for tackling sustainability concerns of biogas from energy crops:

1. Production of biogas may have substantial effects in terms of land use and climate change induced by a change in land use or deforestation. This effect might come directly from growing energy crops. However, it can also come e.g. from supporting energy production, as long as biogas production is not completely autonomous or does not cover the energy needed for the cultivation of energy crops.

2. For some feedstocks, it is likely that at least a share of them is imported from other countries, therefore, shifting the environmental impact away from the countries, where a biogas plant is located.

3. For other resources necessary for biogas plant construction and cultivation of the energy crop, the majority of the impact is accrued to the same set of countries, independent of the plant location. Therefore, it is typically situated outside of the country, where a biogas plant is located.

If one further looks at the future of biogas production and distribution, there is already some movement towards trading this fuel. Examples are the plans of the German electric utilities company RWE to trade biogas between Great Britain and the Netherlands (en:former, 2018) and inclusion of biogas and feedstocks in the portfolio of companies trading energy commodities (e.g. ACT Commodities). However, long-distance transportation options for biogas, as discussed in Section 2.1, can be somewhat limited, compared to liquid biofuels. For example, to transport biogas overseas, it has to be compressed or liquified, meaning the origin and destination ports need to be equipped respectively and LNG vessels need to be employed. This creates additional

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transportation costs, compared to liquid fuels, and lowers profitability of such trade. Therefore, it is rather likely that biogas – provided it is produced in sufficient quantities – is first traded regionally, where grid connections exist, or between already LNG-equipped locations. Another option is that, instead of the final product, the feedstock will be traded. Trade in agricultural products is very well established, and the trend of trading energy crops for biofuels in general and biogas in particular was already visible in Europe in the early 2010s (Kalt & Kranzl, 2012; Pagh-Schlegel & Elkjær, 2012).

In view of these considerations, it is likely that the three observations outlined above will be increasingly important in the future. Therefore, they need to be taken into account when promoting biogas development around the world. In the next section we will review how some existing regulations are already able to tackle these challenges. Based on this, we will then formulate our policy recommendations.

5. Sustainable biogas policy: the EU’s legal framework

5.1. Biofuels in EU law: targets and sustainability criteria

The EU is widely reputed as a leader of international climate action (Bogojevic, 2016), having substantially contributed to the development of the international legal regime on climate change (Oberthür, 2018). Renewable energy has traditionally represented a proactive area of the EU’s policymaking, as the RE targets were already enshrined in the 2001 Renewable Energy Directive (RED 2001) and subsequently updated under the 2009 Renewable Energy Directive (RED 2009) and the 2018 Renewable Energy Directive (RED 2018). Along with the general RE targets at the Member State or at the EU level, specific sub-targets have been enacted with a view of promoting the energy transition in the transport sector. At first, such targets were enshrined in the 2003 Biofuels Directive (Biofuels Directive, 2003). Subsequently, targets for renewable energy in transport have been incorporated into the RED 2009 and, most recently, a target of 14% renewable energy in transport by 2030 is foreseen under Article 25(1) RED 2018.

In order to reach their renewable energy targets, several EU Member States have adopted different kinds of support schemes, such as feed-in tariffs (FIT), feed-in premium (FIP), tradable green certificates and auctions (Banja et al., 2019). Moreover, further policy measures have also contributed to a steady increase in the share of bioenergy, in some cases specifically encouraging the deployment of biogas and biomethane. A case in point is the Alternative Fuels Infrastructure Directive (AFID Directive), which includes minimum requirements for the build-up of refueling points for liquid natural gas (LNG) and compressed natural gas (CNG) (Van Grinsven et al., 2017). As proven by the recent Eurostat data, the EU policy activism has contributed to a steady increase of the share of bioenergy (including energy from the agricultural biomass, the forest biomass and the renewable waste), which grew from 5.9% in 2005 to 10.3% in 2017 (Banja et al., 2019).

However, incentives for biofuels production have also triggered, in some cases, the conversion of agricultural land into land dedicated to the cultivation of energy crops. The biogas sector, along with other biofuels, is part of this phenomenon, determined inter alia by the higher methane yield of energy crops, compared to manure and other sources of agricultural waste. In the case of
Germany, for instance, biogas production from energy crops significantly outweighs its production from industrial and agricultural waste (Eyl-Mazzega et al., 2019).

Following the adoption of the RED 2009, the EU legislator has taken specific countermeasures to reduce the risks connected to an indiscriminate expansion of biofuel production from energy crops. Such measures, known as ‘sustainability criteria’, address both ‘carbon-related’ and ‘non carbon-related’ concerns. In particular, ‘carbon-related’ encompasses the necessary reduction in the GHG emissions that needs to be achieved by biofuels against their fossil fuel comparators (Olsen et al., 2016). ‘Non-carbon related’ concerns, on the other hand, pertain to nature conservation and biodiversity aspects of land use, also known as ‘direct land-use change’ (DLUC), as well as to the risk that part of the demand for biofuels will be met by increasingly devoting land to agriculture, a phenomenon known as ‘Indirect Land-Use Change’ (ILUC) (European Commission, 2010). The RED 2009 took into account both carbon-related concerns and non-carbon related concerns, with the exclusion of ILUC. It introduced a minimum standard of 35 % GHG emission savings from the use of biofuels and provided that ‘sustainable’ biofuels could not be sourced from certain protected areas (e.g. highly biodiverse grassland, wetlands, continuously forested areas) (RED 2009, Article 17). For what concerns ILUC, instead, the normative framework was integrated by the adoption of the 2015 Indirect Land-Use Change Directive (ILUC Directive). It introduced an overall 7% limit of biofuels from food crops, as well as the category of ‘advanced biofuels’, i.e. biofuels that are not in competition with food crops (ILUC Directive, recital (5)).

Importantly, the promotion of ‘sustainable’ biofuels in the RED 2009 did not entail an absolute ban on ‘non-sustainable’ biofuels. Instead, compliance with the sustainability criteria is required for biofuels to enjoy a threefold set of benefits: (a) accounting towards the accomplishment of the national renewable energy targets; (b) contributing to the fulfilment of renewable energy obligations, e.g. the mandatory share of renewable energy in transport; (c) being eligible for financial support.

5.2. Sustainable biogas in the 2018 Renewable Energy Directive

In 2018, the EU adopted a new Renewable Energy Directive (RED 2018), which largely builds upon the previous RED 2009 and enhances the legal framework for the promotion of advanced biofuels. Most notably, the RED 2018 introduces a specific sub-target for a share of 3,5 % advanced biofuels by 2030 (RED 2018, Article 25(1)). Under the RED 2018, advanced biofuels can be counted for twice their energy content when calculating their contribution towards the target for renewable energy in the transport sector. Moreover, the technological development and deployment of advanced biofuels constitutes one of the elements to be included in the ‘Union Bioenergy Sustainability Report’, a biennial progress report to be released by the European Commission from 2023 (Governance Regulation (2018), Annex X).

The RED 2018 is particularly relevant for what concerns biogas, as it extends the need to comply with non-carbon related sustainability criteria to biogas production. In fact, the previous RED 2009 only addressed the minimum GHG emissions savings of biogas (RED 2009, Annex V), while the remainder of the sustainability criteria only referred to liquid biofuels. The RED 2018, instead, applies the full range of sustainability criteria also to biogas production, with an exemption for small installations not exceeding a total rated thermal input of 2 MW (RED 2018, Article 29(1)).
Analogously to the RED 2009, also in the RED 2018 compliance with the sustainability criteria is necessary for bioenergy to account towards the renewable energy targets and to qualify for financial support (RED 2018, Article 29(1)). For what specifically concerns ILUC, the RED 2018 is supplemented by the Commission Delegated Regulation (EU) 2019/807 (ILUC Delegated Regulation), which sets specific criteria for the identification of, respectively, high- and low-ILUC risk feedstock.

6 Promoting biogas sustainability: the case for sustainability criteria beyond the EU legal framework

6.1. Global relevance of the EU sustainability criteria

The EU legal framework for biofuels sustainability is widely reputed as an example of ‘pioneering’ legislation (Kulovesi et al., 2009) and one of the most comprehensive and advanced binding sustainability schemes on a global scale (European Commission, 2011). The global relevance of the EU sustainability criteria emerges in particular from the fact that their validity is not limited to the EU borders. On the contrary, for biofuels to enjoy the benefits mentioned above (see RED 2018, Article 29(1)), compliance with the sustainability criteria needs to be proven regardless of whether the feedstock originates from within or outside the EU. Such extraterritorial applicability has given rise to a vivid debate related to the compatibility of the EU sustainability criteria with international trade rules (Olsen et al., 2016; Lydgate, 2012; Scott, 2011; Kulovesi et al., 2009).

Conversely, less scholarly attention has been devoted to the regulation of biofuels sustainability outside the EU legal framework, and especially in developing countries. Undoubtedly, for many developing countries the EU represents an important export market for liquid biofuels (e.g. bioethanol and biodiesel). Therefore, the adoption of stringent sustainability criteria has the potential to significantly affect biofuels production. For instance, the classification of palm oil (often used as a feedstock for the production of biodiesel) as a high-ILUC risk feedstock under the newly adopted ILUC Delegated Regulation has recently given rise to a legal complaint by Indonesia, currently pending before the WTO (WTO, 2019). Despite the global significance of the EU market, this accounts only for a minority share of global biofuels trade (IEA, 2019b). Therefore, the adoption of the sustainability criteria also in extra-EU jurisdictions would be a crucial step to further mitigate the negative impacts associated with biofuels and biogas production.

In a few non-EU countries, some progress has been registered in support of biofuels sustainability. This is the case, for instance, of Brazil, Japan and the United States (Naiki, 2016). On the contrary, sustainability criteria have rarely been adopted in the legal framework of developing countries. A survey of biofuel policies in East African countries, for instance, concludes that ‘generally agrofuel investments have been insensitive to environmental and human rights concerns of vulnerable populations’ (Owino, 2016). The same study holds that, in the East African region, only Mozambique has put in place sustainability criteria in its biofuels policy, known as the ‘Mozambique Biofuel Sustainable Framework’ (MBSF). Even in the legislative framework of developed countries, biofuels sustainability is not taken into account to the same extent as in the
EU sustainability criteria. In the United States, for instance, sustainability considerations have been mostly included in the policy framework of a limited number of States, such as California, whereas less ambitious legislation has been adopted at the federal level (Endres, 2010). Therefore, it seems fair to conclude that the EU sustainability criteria represent the highest available normative standard (Lin, 2011).

In numerous developing countries, the adoption of sustainability criteria is often trumped by the perception that these might represent a trade barrier, slowing down the development of the biofuels market (Owino, 2016). However, previous studies have shown that the indiscriminate promotion of all biofuels, without taking into account the risks associated to land-use change (LUC) and indirect land-use change (ILUC), may turn out to be most harmful particularly for developing countries (Köppen et al., 2013).

In this connection, UNIDO’s work, in partnership with the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP), has already provided a precious contribution for the development of a ‘Biofuels Screening Toolkit’, a list of 11 sustainability criteria whose adoption is recommended to national policy-makers (ibid.). Such criteria partly coincide with those foreseen under the EU framework, but also address further aspects that are not included in the EU sustainability criteria (e.g. the EU criteria only cover environmental considerations, whereas the ‘Biofuels Screening Toolkit’ also takes into account social considerations).

6.2. The way forward for sustainable biogas policies

In this section, we build upon the LCA analysis on biogas sustainability and the legal analysis on the EU sustainability criteria conducted thus far and propose three key takeaways emerging from our interdisciplinary analysis. These, we believe, will support the further development of the ‘Biofuels Screening Toolkit’ (or a similar policy instrument) by UNIDO and its partner Organizations.

Our LCA analysis has shown that the land use and the LULUC-related climate change can become a concern in any country that indiscriminately promotes biogas, regardless of the feedstock used. Moreover, the impact of biogas production might cross the borders even if the plants are located in a single country. The issue is likely to become more and more significant, in light of the rapid growth of the biogas industry. Overall, the EU sustainability criteria represent an appropriate solution to this problem, as they set a limit on land use for biofuels production, set targets on GHG emission savings and apply these rules independently of the location where biofuels and biogas are produced. This way, the EU ensures sustainable production of biofuels and biogas not only within its borders, but also for biofuels and biogas produced elsewhere and exported into the EU market. As a result, it is possible to conceive two possible reactions from third countries. On the one hand, third countries may propose legal challenges against the EU sustainability criteria, claiming alleged violations of WTO rules. On the other hand, third countries may also adopt sustainability criteria in their legal framework and contribute to the enhancement of biofuels and biogas sustainability. The following three recommendations reveal how the EU sustainability criteria can be used as a model to be adopted in extra-EU jurisdictions.
Recommendation #1: Promote the adoption of legally binding sustainability criteria in extra-EU jurisdictions

Compliance with sustainability criteria can be a voluntary, self-driven choice of economic operators, or be mandated by legislative provisions. The EU sustainability criteria for biofuels and biogas represent a hybrid case, as compliance is not formally mandatory, yet it is an essential requirement to receive financial support (Article 29(1) RED 2018). Moreover, the EU sustainability criteria are an example of a so-called meta-regulation, since the European Commission does not directly test biofuels’ compliance with the sustainability criteria, relying instead on a number of external certification schemes (Lin, 2011). Such model has given rise to critique, especially in light of the risk of proliferation of industry-driven sustainability standards (Stattman et al., 2018). However, such concerns are balanced by the fact that, despite the central role played by private actors, verification schemes are subject to regular monitoring by the European Commission and need to be aligned with the sustainability criteria enacted in legal provisions. Thus, the presence of a legislative basis is a key element to ensure a level playing field for the monitoring of biofuels’ sustainability. Here, the legal criteria serve as a common denominator with which private sustainability schemes need to comply. Moreover, the fact that legal rules assign clear benefits for compliance with the sustainability criteria drives the demand for sustainability certifications, thus informing the choices of private economic operators. Ultimately, the EU sustainability criteria appear well-suited to address the sustainability concerns pointed out in Section 4, also with regard to their extraterritorial applicability which incorporates sustainability concerns independently from the place of production of biofuels and biogas.

In light of the above, the enactment of sustainability criteria in binding legislative provisions, represents a positive pathway to increase sustainability in the biofuels sector. It is important that, at the very least, legislative norms provide the minimum requirements for biofuels to be certified as sustainable. At the same time, it is possible to modulate sustainability schemes in such a way that they do not impose an exceptional burden on the public sector. An example would be the use of meta-standards, as it is the case in the EU sustainability criteria.

Recommendation #2: Support a single and clear definition of ‘advanced’ biofuels and biogas

At present, there is a lack of clarity over the definition of ‘advanced’ biofuels. An analysis conducted by the United States Department of Agriculture shows that there is no univocal definition of ‘advanced’ biofuels across different jurisdictions (United States Department of Agriculture, 2019). The RED 2018 defines ‘advanced’ biofuels as those making use of a selected list of feedstocks, illustrated in Annex IX, Part A. In the RED 2018, such biofuels are specifically incentivized, as they can be accounted for twice their energy content towards the renewable energy targets. It is important that, when enacting biofuels sustainability criteria, a clear definition is provided of what constitutes ‘advanced’ biofuels, taking into account the regional impact of a given feedstock (see Section 4). This also means that, in any jurisdiction, this definition should not discriminate between inland and foreign biofuels or feedstocks. One might also say, sustainable consumption of biofuels should be promoted with these criteria, regardless of where they are produced. This way, not only the respective countries will contribute to biofuels sustainability across the borders, but also their main trading partners in the sector will have better incentives to introduce the sustainability criteria in their jurisdictions. Connected to that, the goal should be to
advance a harmonized definition of ‘advanced’ biofuels, through plurilateral or multilateral agreements. If international consensus can be found around a single definition of ‘advanced biofuels’, this may help tackle protectionist policies in biofuel trade, as ‘advanced’ biofuels produced in one country will be considered as such also in other jurisdictions.

Finally, the EU sustainability criteria, as amended under the RED 2018, specifically address the sustainability of biogas, along with other biofuels. The technical section of this paper has shown that the environmental sustainability of biogas production cannot be neglected. Hence, the sustainability criteria, to be enacted in the legislative framework of extra-EU countries, need to specifically cover the biogas sector in their definition of ‘advanced’ biofuels.

Recommendation #3: Link the adoption of sustainability criteria in developing countries with facilitated access to development finance.

The enactment of the sustainability criteria shall serve not as a barrier, but as an opportunity for developing countries to increase their investments in the bioenergy sector (Owino, 2016). International organizations and multilateral financial institutions can play a key role in ensuring that funds are allocated to investments in sustainable bioenergy. For instance the EU recently revised its Common Agricultural Policy (CAP), requiring that Member States establish maximum thresholds for the use of cereals and other starch rich crops, sugars and oil crops (including silage maize), in order for biogas to receive financial support from the European Agricultural Fund for Rural Development (EAFRD) (European Commission, 2014; Commission Delegated Regulation, 2014). The deployment of a similar mechanism on the international plane should similarly be encouraged, for instance by linking financial support for biogas projects to the adoption of sustainability criteria in domestic legislation. In this regard, UNIDO, also in partnership with other international organizations and multilateral development banks (MDBs) should actively support the adoption of sustainability criteria in the developing countries as a condition to gain access to international funding for biofuels and biogas projects.

7. Conclusion

This research moved from the consideration that climate change is an urgent threat, calling for a radical transition in the energy sector. Biofuels, and biogas in particular, have been identified as promising solutions to reduce GHG emissions, with particular regard to their application in the transport sector and the potential to foster the development of a circular waste economy. At the same time, their production can also give rise to significant sustainability threats.

The interdisciplinary analysis carried out in this paper has focused in particular on the environmental sustainability of biogas. Through the development of an LCA analysis, this paper has analyzed the regionalized impact of biogas production against the environmental indicators included in the latest EU Renewable Energy Directive (RED 2018), namely GHG emissions reduction, land-use change (LUC) and indirect land-use change (ILUC). The regionalized LCA analysis has shown that biogas production may have substantial effects in terms of land use and LULUC-related climate change, both directly and indirectly. Sometimes these effects – but especially the impacts of the use of other resources – are shifted away from the countries where
biogas production is located. This makes the potential sustainability threats of biofuels production an international issue.

Based on these results, the second part of this paper has provided an in-depth review of the EU legislation for the promotion of sustainable biogas and biofuels, addressing the most notable features of the EU framework, compared to some extra-EU regulatory experiences. We found that the EU framework can serve as a notable example for promoting sustainability in the biofuels sector.

On the basis of this combined analysis, this paper has provided three policy recommendations for UNIDO to promote the adoption of sustainability criteria in extra-EU jurisdictions, with a special focus on developing countries.
Bibliography


biofuels.


Kulovesi, K., E. Morgera, & M. Muñoz. (2011). Environmental Integration and Multi-Faceted


## Appendix

1. OpenLCA impact categories

<table>
<thead>
<tr>
<th>Group</th>
<th>Impact category</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>climate change</td>
<td>biogenic</td>
<td>kg CO2-Eq</td>
</tr>
<tr>
<td></td>
<td>fossil</td>
<td>kg CO2-Eq</td>
</tr>
<tr>
<td></td>
<td>land use and land use change</td>
<td>kg CO2-Eq</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>kg CO2-Eq</td>
</tr>
<tr>
<td>ecosystem quality</td>
<td>freshwater and terrestrial acidification</td>
<td>mol H+-Eq</td>
</tr>
<tr>
<td></td>
<td>freshwater ecotoxicity</td>
<td>CTU</td>
</tr>
<tr>
<td></td>
<td>freshwater eutrophication</td>
<td>kg P-Eq</td>
</tr>
<tr>
<td></td>
<td>marine eutrophication</td>
<td>kg N-Eq</td>
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<td></td>
<td>terrestrial eutrophication</td>
<td>mol N-Eq</td>
</tr>
<tr>
<td>human health</td>
<td>carcinogenic effects</td>
<td>CTUh</td>
</tr>
<tr>
<td></td>
<td>ionising radiation</td>
<td>kg U235-Eq</td>
</tr>
<tr>
<td></td>
<td>non - carcinogenic effects</td>
<td>CTUh</td>
</tr>
<tr>
<td></td>
<td>ozone layer depletion</td>
<td>kg CFC-11-Eq</td>
</tr>
<tr>
<td></td>
<td>photochemical ozone creation</td>
<td>kg NMVOC-Eq</td>
</tr>
<tr>
<td></td>
<td>respiratory effects, inorganics</td>
<td>disease incidence</td>
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<td>resources</td>
<td>dissipated water</td>
<td>m3 water-Eq</td>
</tr>
<tr>
<td></td>
<td>fossils</td>
<td>MJ</td>
</tr>
<tr>
<td></td>
<td>land use</td>
<td>points</td>
</tr>
<tr>
<td></td>
<td>minerals and metals</td>
<td>kg Sb-Eq</td>
</tr>
</tbody>
</table>

*Table A1. Impact categories for LCA-analysis with OpenLCA.*
2. Maize and sugar beet yields around the world

Figure A1. Yields of maize in tons per hectare. Source: GADM (base map) & EarthStat.org (yield data).

Figure A2. Yields of sugar beet in tons per hectare. Source: GADM (base map) & EarthStat.org (yield data).
3. Overall impact of biogas production: Maize vs. sugar beet

![Figure A3](image1.png)  
*Figure A3. Impact of production of 1m³ of biogas with different feedstocks on climate change.*

![Figure A4](image2.png)  
*Figure A4. Impact of production of 1m³ of biogas with different feedstocks on the use of resources.*
Figure A5. Impact of production of 1m³ of biogas with different feedstocks on the ecosystem quality.

Figure A6. Impact of production of 1m³ of biogas with different feedstocks on the human health.
4. Regional impacts of biogas production (“global” plant location)\textsuperscript{10}

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\textsuperscript{10} The maps in this and further appendices show relative contributions of the respective regions to the overall impact: red stands for high contribution, blue – for low contribution. The drawback of the OpenLCA software is that it does not provide an exact scale for the regionalized results. The illustrative maps should, therefore, be considered as a qualitative, not quantitative reference.
5. Regional impacts of biogas production from sugar beet, different plant locations

a. Brazil (Paraná)  
b. China  
c. Germany  
d. Nigeria

Figure A10. Regional contributions to the impact of biogas production from sugar beet in Brazil, China, Germany and Nigeria on resource use (land)
Figure A11. Regional contributions to the impact of biogas production from sugar beet in Brazil, China, Germany and Nigeria on resource use (fossils)
6. Regional impacts of biogas production from maize, different plant locations

Figure A12. Regional contributions to the impact of biogas production from maize in Brazil, China, Germany and Nigeria on resource use (land)
Figure A13. Regional contributions to the impact of biogas production from maize in Brazil, China, Germany and Nigeria on resource use (fossils)