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A mini-review of biomethane valorization: Managerial and policy implications for a circular resource

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Abstract

The green transition requires renewable energy resources, especially the role of biomass is very crucial as it promotes resource circularity if sustainable substrates are used. This mini-review focuses on green gas derived from biomass called biomethane, which appears to be strategic in the face of soaring energy costs. Hence, combined Strengths, Weaknesses, Opportunities and Threats–Analytic Hierarchy Process analysis is used to compare and evaluate the critical factors. The results provide not only methodological insights through the application of the local–global priority method, but also managerial insights that see biomethane as a winning element for the green transition, fighting climate change and reducing dependence on external energy sources. Subsidies have played a key role in pursuing economic sustainability; however, their use should be reduced over time and measured to the actual contribution related to environmental and social improvement. The results of this work highlight that biomethane development is important to tackle climate change and to be self-sufficient from an energy perspective. This development plan, based on circularity of resources, includes subsidies for small-scale plants, substrates from neighbouring territories, citizen involvement in decision-making processes, valorization of suitable waste from an environmental perspective and stability of political choices.

Keywords

Green transition, biomethane, circular economy, AHP–SWOT, climate change, subsidies

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Introduction

Nowadays, the critical depletion of raw materials and the surge of wastes and residues disposed in the environment are worrying policymakers, always more committed to push society towards strategies able to restore and recycle resources in an effective and efficient way. Therefore, sustainability and sustainable development (United Nations, 2015; WCED, 1987) became an always more challenging and urgent concern worldwide, due to shrinking time constraints available to enact remedies and solutions. In addition, concepts as Circular Economy (CE) can be considered a key driver towards the achievement of Sustainable Development Goals (SDGs) (Velenturf and Purnell, 2021), based on the values of narrowing, slowing and closing of resources' loops (Bocken et al., 2016), to promote economic prosperity, social equity and environmental quality (Kirchherr et al., 2017), to identify new business (Tapaninaho and Heikkinen, 2022) and new models of eco-design (Vacchi et al., 2021a). In this context, until 1990s, technology was considered the main driver to manage to successfully enact restore- and recycle-driven strategies. Its role is strategic towards sustainability (Arrhenius and Büker, 2021; Vacchi et al., 2021b). However, several issues were detected due to both the presence of heavy components of pollutants in wastes (e.g. potentially toxic elements (PTEs)) and the fact that often the treatment process to remove, stabilize or destruct the pollutants generates emissions. Indeed, COP26 revealed that not all countries are keen and able to support the transition, leading to strong inequalities concerning sustainable development, emissions of toxics, economic production drivers, efficiency rates and social impacts. Due to this, the need of a sustainable hand, able to distribute the value among all stakeholders, has been raised in literature (D'Adamo et al., 2022). The public acceptance of projects is a key-element to implement green initiatives (Moustairas et al., 2022). To trigger this action, a multi-disciplinary approach should be used, driven by a systematization of data and information (Acerbi et al., 2021; Sassanelli et al., 2019) – flowing in parallel with resources, energy and wastes through the effective adoption and use of digital technologies bolstering the entire product lifecycle (Sassanelli et al., 2020) – and flanked

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by robust methodologies able to propose solutions to present and future necessities (Rocca et al., 2020).

The issue of waste management is crucial (Loizia et al., 2021; Voukkali et al., 2021), useful to produce energy (Kandasamy and Gökalp, 2015), to be used in the transport sector (Gustafsson et al., 2021) and biomass is a relevant component of the green transition (Bennici et al., 2019; Jeguirim et al., 2019). The growing awareness of the need for safely restoring and valorizing waste and biomass to valuable materials and energy is turning up as a major trend for sustainable development (D'Adamo et al., 2022), able also to recovery and reuse additional products (Ferella et al., 2017). In detail, bioeconomy is defined as a paradigm capable to convert renewable energy resources (RES) biologically deriving from the land and sea – animals (Silva et al., 2020), water (Hildebrandt and Bezama, 2018), crops and agrowaste (Moustakas et al., 2020), forests, etc. – to energy (Fragoso et al., 2021), food (Ragossnig and Ragossnig, 2021) and materials (Lekkas et al., 2021). Several industries are exploiting the results of such paradigm: from agriculture, forestry, fishing and aquaculture, through manufacture of food, beverages, tobacco, bio-based textiles, wood products and furniture, paper, bio-based chemicals, up to manufacture and production of pharmaceuticals, plastics and rubber, liquid biofuels and bioelectricity (European Commission, 2018). The stakeholders belonging to these industries should however look at sustainability as a font of competitive advantage to enable their success in the market (Appolloni et al., 2022). In this domain, there are managerial practices that can be considered best practices to be followed to lead to a circular bioeconomy (Kardung et al., 2021), for example the substitution of non-renewables with biological resources, the cascading use of biomass and minimization of biowaste.

These practices are also valuable for biogas production. A review on the role of biogas towards all SDGs was proposed by Obaideen et al. (2022). Biogas is an example of renewable energy and also considered a secondary energy carrier developed from biodegradable organic flows of materials via anaerobic digestion (Awe et al., 2017). For sure, the recovery of energy from wastes is a model of CE, being able to close both the material and energy cycles (Tomić and Schneider, 2018), and is considered a promising avenue towards sustainability (Baena-Moreno et al., 2021; Lindfors et al., 2019). Indeed, it can have different destination of use: fuel, starting material for chemicals production, hydrogen and/or synthesis gas, etc. (Awe et al., 2017).

The difference between biogas and biomethane is clarified by the International Energy Agency. Biogas is defined as a combination of methane, CO_2 and other gases created through anaerobic digestion of organic matter in an anaerobic environment. Instead, biomethane is derived from a set of different substrates (e.g. crop rests, animal fertilizer, organic part of municipal solid waste and wastewater mud) and is a nearly pure font of methane and derives either by biogas upgrading or by gasification of solid biomass followed by methanation (International Energy Agency, 2021; Sfetsas et al., 2022). It can be allocated to natural gas grids, used as fuel for vehicles or also converted to supply cogeneration units. Biomethane adoption can trigger new prospects for society on many levels (Haider et al., 2020; Zhu et al., 2019). However, issues related with biogas cleaning and upgrading technologies, its composition, upgrading efficiency, methane recovery and loss should be considered (Ndubuisi-Nnaji et al., 2020). In addition, the lack of public acceptance towards biogas–biomethane plants and the defectiveness of related regulations have been highlighted in literature (Budzianowski and Brodacka, 2017). Due to this, even if biomethane is widespread in Europe, it is still not fully exploited (Prussi et al., 2021). Indeed, it can be worth assessing its potential impact globally (Schmid et al., 2019), being promising its environmental contribution, both in the retrieval of the organic fraction of municipal solid waste (Cremiato et al., 2018) and of by-products (e.g. animal fertilizers, wastes from agriculture and the agro-industry) (Valenti et al., 2018).

The trend of biomethane plants is clearly growing as highlighted by the European Biogas Association: it went from 483 in 2018 to 729 in 2020 to achieve an increase of 40% during 2021 (reaching the number of 1023 production plants). Germany has the most significant number of plants followed by France which, together with Italy and Denmark, has recorded the highest increase in the number of plants in the last year (European Biogas Association, 2022).

Biomethane is a resource that can foster CE models (D'Adamo et al., 2021), and Strengths, Weaknesses, Opportunities and Threats–Analytic Hierarchy Process (SWOT–AHP) analyses are proposed in the literature to identify strategic factors useful for the development of the sector (Fernández-González et al., 2020). For this reason, this work uses the approach proposed by D'Adamo et al. (2020). The aim of this research is to give support tools to policymakers, researchers, companies and citizens to have an overview of biomethane, to indicate a priority among multiple criteria and to identify the lines to be implemented to foster the development of biomethane in new markets. Managerial implications and policy suggestions are obtained based on the SWOT–AHP analysis conducted.

Materials and methods

The decision-making models are useful to resolve all processes in which multiple factors are compared in order to identify the most optimal solution. The AHP approach is widely used in the biomass energy field (Barry et al., 2021; Reißmann et al., 2018), since as demonstrated by Saaty (1980), it identifies a list of priorities obtained through pairwise comparisons based on expert judgments. In particular, several papers highlight that AHP is useful for investigating environmental issues (Hermann et al., 2007; Ilicali and Giritli, 2020).

A SWOT analysis is a strategic planning tool that highlights the characteristics of an energy resource and its relationship to the internal and external environment (Chanthawong and Dhakal, 2016). In addition, this method is considered suitable for assessing sustainable issues (Voukkali and Zorpas, 2021; Zorpas et al., 2018).

Figure 1. Research process.

The analysis of this study starts from the framework proposed by D'Adamo et al. (2020), in which a SWOT–AHP is applied to the biomethane sector to understand what elements can foster its development. A similar approach is also proposed in the literature by other authors (Fernández-González et al., 2020). However, the strength of SWOT–AHP is that it can be applied in multiple areas: reuse (Vardopoulos et al., 2021), hydrocarbons (Tsangas et al., 2019) and manufacturing (Görener et al., 2012). Generally multicriteria decision analysis (MCDA) resolves conflicting situations by providing a judgement of a more viable alternative (Zorpas and Saranti, 2016).

Consequently, the objective of this article follows the methodological approach already proposed in literature, but aims to analyze how the incidence of these factors changes over time by also choosing a different panel of experts. The novelty of the work is related to the interpretation of the results and its managerial implications obtained through a quantitative analysis.

This method consists of the following steps (Figure 1):

- Step 1. Identification of experts
- Step 2. Identification of SWOT factors
- Step 3. Presentation of local and global priority
- Step 4. Aggregation of comparisons provided by experts
- Step 5. Feedback from experts.

Identification of experts

The previous analysis (D'Adamo et al., 2020) showed that experts belonging to different categories of stakeholders did not give different indications, but the variations in judgements came from the territories to which they belonged. In particular, experts belonging to European countries where biomethane was developed gave weight to the advantages, whereas disadvantages were proposed by those living in European countries where biomethane was less developed. This article uses the following assumptions. The number of experts is always chosen equal to 20, and the analysis is restricted to academia – Supplemental Table A1. The idea is to see how the results change depending on the experts, but this aspect is also influenced by the different time period considered. Conversations with the experts revealed how in this work it is the time factor that plays a key role. The invitation was made through an email or via LinkedIn, proposing the purpose of the study and presenting previous work as a starting point if requested. It was specified that this analysis was intended to capture new insights in light of energy changes. In fact, the previous analysis was attached but without providing a critical analysis of the results and so it can be interpreted as input data. The experts were selected and chosen through Scopus among those who had published an article with the word biomethane in the title and generally, characterized by knowledge about the biogas–biomethane chain. Another requirement was the years of experience, for which the minimum value of 10 years was chosen (always through Scopus). The content of the email reported that only the first 20 identifiers that gave a positive response would have been chosen. The interviews were conducted between December 2021 and January 2022, and all experts requested to receive the previous research as an attachment, since belonging to the literature did not influence their choice. Each interview lasted on average about 1 hour in which the subject of the study was proposed and the excel sheet and related calculations were described.

Once the results were completed, each expert provided the results regarding the weights obtained and the consistency ratio (CR) value obtained. Their privacy is maintained, as the time required to respond to surveys is precious time for all academics, and in the initial email, it was specified that all rules regarding privacy and data processing would be respected. In addition, the process of selecting experts is made easier when the greater the number of invitations sent out. However, a winning element at this stage to avoid low participation is that the invitation must come from an official email, which the time taken will be short, and by the willingness you have shown in responding to invitations from previous surveys.

Identification of SWOT factors

The same number of critical factors has been set for each of the four quadrants of the SWOT analysis to make them comparable. As noted by Brudermann et al. (2015), the SWOT–AHP approach is suitable for evaluating the biogas sector. Table 1 proposes a framework proposed by D'Adamo et al. (2020) in which the factors related to the biomethane are defined according to the literature. In fact, the choice of each factor is made according to this source, and the combined SWOT–AHP analysis provides a quantitative assessment that determines which criteria are most relevant to consider and indicates the health of an industry.

The dimension of the AHP comparison matrix ranges from 1 to 10 factors, but it is typically set to 7 ± 2. For this reason, five criteria are identified (consistent with the value requested by Saaty (2008)) for each quadrant for a total of 20. This allows for a homogeneous analysis when comparing SWOT groups. The choice of criteria is made in accordance with the previous analysis because otherwise it was impossible to make a comparison. However, the analysis of recent literature did not reveal other critical factors.

Table 1. Identification of SWOT factors.

	Strengths	References
S1	Number of actors involved	Ammenberg et al., 2018
S2	Utilisation of available resources	Brudermann et al., 2015
S3	Technical requirements well-known	Clancy et al., 2018
S4	Recovery/selling of additional products	Hao et al., 2018
S5	Additional source of income	Brudermann et al., 2015
	Weaknesses	
W1	Quality of technical parameters	Brudermann et al., 2015
W2	Low financial strength of small plants	Brudermann et al., 2015
W3	Lack of awareness	Herbes et al., 2018
W4	Uncertainty of subsidies	Chan Gutiérrez et al., 2018
W5	Inadequate raw material	Ardolino et al., 2018
	Opportunities	
O1	Can be blended with natural gas	Scarlat et al., 2018
O2	Reduced dependency on energy imports	Brudermann et al., 2015
O3	Targets/constraints to reach	Veum and Bauknecht, 2019
O4	Climate change	Brudermann et al., 2015
O5	Multi-functionality of biomethane	Brudermann et al., 2015
	Threats	
T1	Potential dilemma with other RES	Daniel-Gromke et al., 2018
T2	Low social acceptance	Brudermann et al., 2015
T3	Schemes time-limited	Horschig et al., 2019
T4	Food vs fuel dilemma	Brudermann et al., 2015
T5	Feed-in-tariff depends on policy	Brudermann et al., 2015

Source: Adapted by D'Adamo et al. (2020).

It should be noted that after the identification and selection of the expert, an email was sent containing the material necessary to conduct the evaluations. A very short time frame was proposed before to attend the survey (max 72 hours) within which to communicate if one disagreed with the factors identified and to propose any corrections. During this phase, no critical issues emerged, and the main reason given by the experts was the origin of the document, which gave solidity to what was proposed.

Presentation of local and global priority

A comparison among 20 criteria is very complex, and for this motive, an approach based on the initial calculation of a local priority (restricted group of criteria) has been introduced for the subsequent one of a global priority (in which they are all aggregated). This choice allows us to compare a very significant number of criteria, which would not be possible with a simple AHP.

Below, the following definitions are explained:

- 'Local priority' measures the relevance of a factor within the same SWOT group and therefore consists of four analyses that consider 5×5 matrices.
- 'Category priority' measures the relevance of a SWOT group; therefore, it is made up of one analysis that considers a 4×4 matrix.
- 'Global priority' measures the relevance of all the SWOT factors and is calculated as the product of local priority and category priority.

For each matrix, experts were offered a nine-level scale (Saaty, 2008): 1 → Equally preferred; 2 → Equally to moderately; 3 → Moderately preferred; 4 → Moderately to strongly; 5 → Strongly preferred; 6 → Strongly to very strongly; 7 → Very strongly preferred; 8 → Very strongly to extremely and 9 → Extremely preferred.

The final result of the AHP is to have all the SWOT factors normalized to 1. Furthermore, to verify the goodness of the analysis conducted, the CR was calculated, whose value must be less than 0.10 (Saaty, 2008). To allow the experts to carry out a self-check, this value was also calculated in the excel sheet. It should be noted that all experts preferred to complete these assessments not during the interview.

Aggregation of comparisons provided by experts

The CR provided within the excel file is a useful tool for practitioners as it gives them immediate feedback on what they have worked out. CR is identified as a test of model robustness. Decision-making processes are made up of different pieces of information, and the AHP aims to rank and prioritize them. The experts have provided a total of 50 pairwise comparisons, of which 40 were obtained referring to local priorities and 10 referring to category priorities. Once the different responses were received, the first step was to verify that indeed the CR was lower than 0.10.

In order to aggregate all the data, it is necessary to note that all the experts were assigned the same relevance. We proceed to aggregate all the weights associated with the local priority of the SWOT factors and the category priority of the SWOT groups. At this point, it is possible to obtain the average value for both local priority and category priority. The next step is to calculate the global priority for each SWOT factor.

Feedback from experts

The survey consists of a second phase in which an interview is conducted to examine the results proposed in the first phase. We would like to point out that in the initial email invitation, it was specified that the survey consisted of these two phases and an indicative time frame in which it would be carried out was indicated. It comes them anticipated to them via email the result obtained asking comments on the results through a video call. The duration is about half an hour, and the question of analysis is what indications they identify from this analysis to encourage the development of biomethane in a country that does not have a development of this renewable source.

Results

This article aims to provide an overview of the biomethane industry by providing not only managerial but also policy assessments. MCDA-AHP is proposed as a methodology for this purpose. The category priority evaluation is proposed in the first sub-section, whereas the local priority in the second sub-section. Aggregating these weights, it is possible to calculate the global priority in the third sub-section. A second phase of the survey is conducted in which the results are proposed and asked to evaluate if these factors are able to support the development of new markets (in the fourth sub-section).

The assessment of category priority

Supplemental Table A2 proposes all the values obtained by the experts, identifying the average value associated with the category priority (Table 2). For privacy reasons, it should be noted that the number assigned to the expert does not coincide with the number proposed in the previous section. For example, the expert no. 1 assigns the greater weight to the opportunities (40%, i.e. 0.40) and to follow there are threats (0.30), strengths (0.20) and weaknesses (0.10).

The results show that unlike the previous analysis (D'Adamo et al., 2020), the experts' opinions do not identify two distinct groups. It is likely that the development of biomethane in recent years has led to this result, and it is worth highlighting that the factors classified as 'advantage' have a percentage weight of 59.5% greater than those classified as 'disadvantage' at 41.5%. In particular, all the experts agree in assigning the highest value to opportunities, which obtains an average value of 0.3775. External factors tend to have greater weight than internal ones (65% vs 35%). Experts during the survey have highlighted that what weighed on this choice were the factors present within the category. So the approach used was to grade all five factors per category, which explains why the external component received more attention. Also probably playing a key role is the expanding sector seen as a solution to climate change and as supporting the green transition. These aspects are seen as changes coming from the outside world. Moreover, another observation is that to balance the judgement between the 'advantage' side and the 'disadvantage' one, the second category is that one of the threats with a medium value of 0.2750. The same approach is proposed also for the internal factors: strengths with 0.2175 and weaknesses with 0.1300.

Finally, the direct comparison with the previous analysis has shown that opportunities and strengths have gained 0.1465 and 0.0545 as an average. At the same time, the other two sources have decreased: weaknesses −0.1230 and threats −0.0078.

The assessment of local priority

The analysis is carried out at the level of each individual category (strengths, weaknesses, opportunities and threats), where the five factors are compared to each other. It should be noted that again, the number of the expert does not correspond to what is proposed in the previous section.

Strengths

Supplemental Table A3 aggregates the local priority for the SWOT quadrant associated with the strengths (average values are proposed in Table 2). The results show that the factor considered most important is not the same for experts: nine of them prefer S5, whereas S2 and S4 are chosen as priority by seven and four experts.

However, the results show that among these three factors, the numerical values identify a non-marginal difference. In fact, the factor considered most important is S5 (additional source of income) with 0.3050, preceding S4 (recovery/selling of additional products) and S2 (utilization of available resources) with 0.2650 and 0.2600, respectively. The CE is not only linked to the recovery of waste but also to its valorization. In this way, it is possible to obtain an additional income. At the same time, this is verified if the plant turns out to be profitable. Economic analyses on the subject stress that this occurs in the presence of multiple critical variables such as the presence of subsidies, type of substrates and size of plants (Baena-Moreno et al., 2021; Cucchiella et al., 2019). It should be noted that for some substrates, such as organic fraction from municipal solid waste, have specific revenues to be managed. The order of ranking is consistent with what was proposed in the previous analysis; however, if the factor S5

Table 2. The average value is expressed in relative terms normalized to 1.

	Category Priority				
	Strengths	Weaknesses	Opportunities	Threats	
Average value (new analysis)	0.2175	0.1300	0.3775	0.2750	
Average value (previous analysis)	0.1630	0.2530	0.2310	0.3530	
	Local priority (strengths)				
	S1	S2	S3	S4	S5
	Number of actors involved	Utilisation of available resources	Technical requirements well-known	Recovery/selling of additional products	Additional source of income
Average value (new analysis)	0.0775	0.2600	0.0925	0.2650	0.3050
Average value (previous analysis)	0.1490	0.1820	0.1670	0.1900	0.3120
	Local priority (weaknesses)				
	W1	W2	W3	W4	W5
	Quality of technical parameters	Low financial strength of small plants	Lack of awareness	Uncertainty of subsidies	Inadequate raw material
Average value (new analysis)	0.0650	0.2125	0.2200	0.2925	0.2100
Average value (previous analysis)	0.1560	0.1530	0.2030	0.2670	0.2210
	Local priority (opportunities)				
	O1	O2	O3	O4	O5
	Can be blended with natural gas	Reduced dependency on energy imports	Targets/ constraints to reach	Climate change	Multi-functionality of biomethane
Average value (new analysis)	0.0900	0.2975	0.2125	0.3150	0.0850
Average value (previous analysis)	0.1570	0.2030	0.2540	0.2410	0.1450
	Local priority (threats)				
	T1	T2	T3	T4	T5
	Potential dilemma with other RES	Low social acceptance	Schemes time-limited	Food vs fuel dilemma	Feed-in-tariff depends on policy
Average value (new analysis)	0.1275	0.1425	0.2125	0.2100	0.3075
Average value (previous analysis)	0.1390	0.1270	0.1900	0.1720	0.3730

sees its weight reduced slightly, there is a significant growth of the other two factors S4 and S2. Experts believe that the concept of CE asks for the contribution of these aspects, since it is not only a matter of producing energy but also a matter of recovering all the potential components (e.g. digestate and food-grade CO_2), and at the same time, the potential is more significant since it deals with resources currently available and not recovered. Thus, it ties into the concept of unrealized shared value. The growth of these two factors also corresponds to a significant reduction of the other two factors: S1 (Number of actors involved) and S3 (Technical requirements well-known).

Weaknesses

Supplemental Table A4 aggregates the local priority for the SWOT quadrant associated with the weaknesses (average values are proposed in Table 2). The results show that the factor considered most important is not the same for experts: more than half (12) of them prefer W4, whereas W2 and W5 are chosen as priority by 3 experts. Last two experts opt for W3.

The results clearly show that the local priority associated with W4 (uncertainty of subsidies) is the most relevant with 0.2925 and has a higher value than that proposed in the previous analysis. The issue of subsidies has played a key role in the development of the sector (Baena-Moreno et al., 2020), since the green transition requires a conversion of the energy mix. It has been highlighted above how economic analyses depend on this variable; therefore, its variation definitely affects profitability. In particular, its instability can increase the risk, driving away potential investors. The W3 factor (lack of awareness) registers a 0.2200, a slight increase, as the theme of information campaigns to promote good consumer practices is a very important issue. In particular, the literature that social acceptance increases when local use of resources is used (Fedorova and Pongrácz, 2019). A very significant growth is registered by the W2 factor (low financial strength of small plants). Also in this case, economic analysis allows us to define that large plants have significant advantages in terms of profitability. However, CE practices suggest the relevance of having an energy mix composed of small plants for which it is also appropriate to favour different incentives (D'Adamo et al., 2021). In particular, the issue is even more felt in a perspective of energy communities. The W5 factor (Inadequate raw material) shows a slight reduction but such as to push it from second to fourth place for this specific category. On this aspect, it is advisable that incentive systems protect substrates that actually provide a sustainable advantage proven by life cycle analysis. Factor W1 (quality technical parameters) is not relevant since the technology is suitable for mixing biomethane with natural gas.

Opportunities

Supplemental Table A5 aggregates the local priority for the SWOT quadrant associated with the opportunities (average values are proposed in Table 2). The results show that the factor considered most important is not the same for experts: more than half (11) of them prefer O4, followed by O2 with 8 experts. Another expert chooses O3.

This category shows that experts believe that biomethane (but in general, the analysis concerns all renewable energies) has the objective of promoting actions and practices to combat climate change and to reduce geopolitical risks by producing energy internally. The idea that the green revolution has started late seems evident, given the climate changes that all citizens can witness. However, not all countries have understood the magnitude of the problem. Sustainability is seen as a competitive advantage for businesses (Appolloni et al., 2022) and the development of renewable energy can lead to the achievement of sustainable goals (Malik et al., 2019). The strong price fluctuation in the energy sector, particularly during the period covered by the survey, probably prompted many experts to highlight the relevance of this factor. It is a strategic lever in national energy plans, but then often its relevance can be overshadowed because it is not possible to quantify in numerical terms the relevance of producing energy internally and no longer depending on external actors and especially being able to better regulate market turbulence. The ranking places the factor O4 (climate change) with 0.3150 followed by the factor O2 (reduced dependency on energy imports) with 0.2975. These two factors, and in particular O2, are up on the previous analysis. The O3 factor (targets/constraints to reach) moves from the first to third place, reducing its weight, but maintaining a weight of 0.2125. The idea that seems to emerge is that renewable plants are also implemented in order to meet the imposed targets, but these are not the driving elements. On the other hand, O1 (can be blended with natural gas) and O5 (multi-functionality of biomethane) are of little importance, even if their weight has a decreasing value.

Threats

Supplemental Table A6 aggregates the local priority for the SWOT quadrant associated with the threats (average values are proposed in Table 2). The results show that the factor considered most important is not the same for experts: more than three quarters (16) of them prefer T5, followed by T4 with 4 experts.

The last SWOT quadrant highlights that the T5 factor (feed-in-tariff depends on policy), which came first in terms of global priority, has lost some points of relevance, but is still the most relevant among local priorities with 0.3075. This data could be in contrast with what was seen previously in which emphasis was placed on the role of subsidies. However, the key to interpretation may be another. This factor remains relevant in the eyes of the experts, but its reduced relevance can be explained as the development of the sector in various markets may have led to a reduced dependence on the incentive system. This aspect is typical of renewable sources that begin to be competitive by reducing their costs. Later, we found factors T3 (schemes time-limited) and T4 (food vs fuel dilemma) with a weight of 0.2125 and 0.2100, respectively. The presence of a subsidy value plays a key role, but so does its time duration. Political instability and changes in government policies can push companies/investors into uncomfortable situations where the risk components are drastically changed. Application of the sustainable hand concept can reduce this effect (D'Adamo et al., 2022). However, the history of some countries has shown that biomethane development should not involve substrates that could be diverted from other uses. The relevance of growth related to the energy sector is paramount, but the relevance of growth related to food is equally important (Jackson et al., 2021). Factors T2 (low social acceptance) and T1 (potential dilemma with other RES) are seen as less relevant.

The assessment of global priority

The final step of the analysis is to rank all the SWOT factors. In particular, Table 3 proposes a comparison with previous work (D'Adamo et al., 2020) since an important role of decision analysis is also to provide a time trend. Figure 2 shows the comparison of the delta average value. Thus, for example, the factor O4 shows an increase of 0.0634 in terms of global priority and 0.0740 as local priority.

The first result that emerges is that the position in the ranking of all the factors has been modified. In the previous analyses, it was specifically analyzed how the weight of individual venues has changed, but what significantly influences the new ranking is the weight of the category priority. Among the top five factors, we found four factors related to biomethane 'advantage' side that increased from 39.4% to 59.5%, of which almost 38% associated with opportunities. This determines that O4, O2 and O3 occupy the first, second and fourth positions. This depends on the local

Table 3. Global priority of SWOT factors.

SWOT factors		New analysis		Previous analysis	
		Value	Ranking	Value	Ranking
S1	Number of actors involved	0.0169	19	0.0243	20
S2	Utilization of available resources	0.0566	9	0.0297	18
S3	Technical requirements well-known	0.0201	18	0.0273	19
S4	Recovery/Selling of additional products	0.0576	8	0.0309	17
S5	Additional source of income	0.0663	5	0.0509	9
W1	Quality technical parameters	0.0085	20	0.0395	13
W2	Low financial strength of small plants	0.0276	16	0.0388	14
W3	Lack of awareness	0.0286	15	0.0513	8
W4	Uncertainty of subsidies	0.0380	11	0.0676	2
W5	Inadequate raw material	0.0273	17	0.0558	6
O1	Can be blended with natural gas	0.0340	13	0.0362	15
O2	Reduced dependency on energy imports	0.1123	2	0.0468	11
O3	Targets/Constraints to reach	0.0802	4	0.0586	5
O4	Climate change	0.1189	1	0.0555	7
O5	Multi-functionality of biomethane	0.0321	14	0.0335	16
T1	Potential dilemma with other RES	0.0351	12	0.0490	10
T2	Low social acceptance	0.0392	10	0.0449	12
T3	Schemes time-limited	0.0584	6	0.0670	3
T4	Food vs fuel dilemma	0.0578	7	0.0608	4
T5	Feed-in-tariff depends on policy	0.0846	3	0.1317	1

priority that sees the three factors equal to around 83% of the total in their quadrant. The same happens for the strengths (in which we find S5 in fifth position). On the other hand, the first three factors have a weight of around 73% in the other two quadrants, but it should be noted that in the case of weaknesses, the fourth factor is very close to the third.

The category priority does not imply a better result in terms of global priority. The distribution of local priority is fundamental. For example, the last factor of threats (T1) precedes the last two of opportunities (O1 and O5). In particular, we find the T5 factor in third position (while it was first) and then, among the 'disadvantage' factors, there are the T3 and T4 factors in sixth and seventh position. None of the weakness factors are in the top 10 positions.

The second result that emerges is the methodological one, as the work expresses in detail how multicriteria analyses and evaluating their trend over time allow to support decision makers. The delta category priority is able to change the sign of performance between the delta global priority and the delta local priority. For example, the factors S5 and O3 are considered less important in pairwise comparisons with the other factors in their quadrant, but an increase in their category priority also leads to an increase in global priority. An opposite situation occurs for the factors W2, W3, W4, T2, T3 and T4, which present an increase in their weight in their respective quadrants but lose in global priority due to the reduction associated with the 'disadvantage' side of biomethane.

Discussion

Experts believe that biomethane is viewed with more confidence as it has proven to be a renewable source capable of making a decisive contribution in the green transition in which all countries are called upon to play their part. In particular, there has been a focus on the key role that CE practices can bring. On the one hand, economic sustainability must be verified by a reduction in costs (difficult to imagine in undeveloped markets) and revenues in which subsidies play a fundamental role. However, policy choices have a fundamental impact. The values of incentives should be measured on the basis of actual environmental benefits; therefore, analyses are required that testify to actual environmental sustainability. It should be noted that in this interpretation, a clear distinction should be made between the urgency of green energy and that associated with food. Energy cannot take away land for food production activities, but it is necessary to use all available and uncultivated areas. Subsidies should therefore support only those substrates that continue in that direction. In addition, particular attention has been paid to the size of the plant. As highlighted in the literature (Baena-Moreno et al., 2020; D'Adamo et al., 2021), small plants deserve special attention because their role will be strategic in less densely populated areas or where there is less availability of substrates. This aspect leads to social sustainability, as citizens are required to be self-sufficient and therefore should take responsibility for the waste they produce. Citizen involvement is therefore considered important. However, it is the task of the policymaker to reward good practices through benefits to be reaped in good waste collection practices and by encouraging industrial symbiosis models, since sharing resources can be a competitive advantage in the face of resource scarcity or inflationary phenomena. Biomethane is not competitive with other renewable forms because there is a need of all renewable sources. Its flexibility is a key element because

Figure 2. Delta average value of SWOT factors.

allows it to be used in different applications. However, particular attention should be paid to the transport sector, where there are currently greater demands to counteract the use of fossil fuels and where there is potentially less availability of energy resources. This work underlines the need to have good waste collection and synergies between different actors

Another interesting result is to see a more responsible attitude whereby these plans are not developed just because there are targets to be met, but also why it is necessary to do so. It is worth emphasizing how the desire for energy independence can play a stronger stimulating factor than the target to be met. The higher energy costs can be reduced if companies are also self-sufficient from an energy point of view. Certainly, the effort is great, but the challenge of the green transition is epochal and calls for a very important change of pace. Subsidies are important, but their relevance may be likely to decline provided that political stability is assured. In addition, subsidies should not be provided for fossil sources but only for actions that actually produce benefits to protect ecosystems. CE models aim at an effective and efficient use of resources, and biomethane can valorize a variety of wastes providing sustainable benefits.

There is a need to create an energy model that minimizes foreign dependence and reduces geopolitical risks. At the same time, the choice of energy suppliers is desirable not to be based on a single supplier such as to reduce energy problems in times of serious crisis, such as that which is determined by the conflict in Ukraine. Sustainability is a challenge that cannot be postponed, but the transition is also based on the use of gas as not all countries are ready to rely solely on the use of renewable sources. The results of this work can be applied in all those contexts where the biomethane sector is not developed and the circular bioeconomy is an enabling factor for sustainability.

Conclusions

Biomethane is a virtuous example of a circular bioeconomy, which is seen as an enabler towards sustainability. The current crisis caused by the conflict in Ukraine has pushed prices up dramatically with negative repercussions on citizens and businesses. However, the presence of speculative phenomena is evident, and politics could take action by lowering prices in order to protect social welfare. The use of fossil fuels needs to be reduced, but where there is a risk that some productive activities will come to a halt or that citizens will pay very high prices, the sustainable transition can provide for their use. The important thing is that this does not reduce the development of renewable sources.

The time evolution of the sector is important, and this work continues a research activity in which a new panel of experts, not limited to Europe, is considered. The objective is to extend good practices in new markets providing managerial implications. However, the work has some limitations since the specific analysis of substrates can lead to the identification of other factors and new business models, also providing comparisons among these elements. However, geopolitical risk drives the use of all substrates that support domestic green gas production as long as these substrates meet sustainability requirements. The future direction of the work may tend towards social analyses in which the public opinion on these renewable sources is assessed, comparing the perception among different countries and cooperative models (e.g. energy communities and industrial symbiosis) should be conducted in which different production realities could collaborate with each other to exploit economic advantages and reduce environmental impact. Furthermore, the purpose of use should be compared, depending on the country's needs in different sectors. This work has confirmed how biomethane is a source of circularity of resources and its valorization allows to reduce the level of emissions, reduce geopolitical risks, develop new economic opportunities and create forms of social aggregation.

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References

Acerbi F, Sassanelli C, Terzi S, et al. (2021) A systematic literature review on data and information required for circular manufacturing strategies adoption. *Sustainability* 13: 2047.

Ammenberg J, Anderberg S, Lönnqvist T, et al. (2018) Biogas in the transport sector --actor and policy analysis focusing on the demand side in the Stockholm region. *Resources, Conservation and Recycling* 129: 70-80.

Appolloni A, Chiappetta Jabbour CJ, D'Adamo I, et al. (2022) Green recovery in the mature manufacturing industry: The role of the green-circular premium and sustainability certification in innovative efforts. *Ecological Economics* 193: 107311.

Ardolino F, Parrillo F and Arena U (2018) Biowaste-to-biomethane or biowaste-to-energy? An LCA study on anaerobic digestion of organic waste. *Journal of Cleaner Production* 174: 462–476.

Arrhenius K and Büker O (2021) Comparison of different models to calculate the viscosity of biogas and biomethane in order to accurately measure flow rates for conformity assessment. *Scientific Reports* 11: 1660.

Awe OW, Zhao Y, Nzihou A, et al. (2017) A review of biogas utilisation, purification and upgrading technologies. *Waste and Biomass Valorization* 8: 267–283.

Baena-Moreno FM, Malico I and Marques IP (2021) Promoting sustainability: Wastewater treatment plants as a source of biomethane in regions far from a high-pressure grid. A real Portuguese case study. *Sustainability* 13: 8933.

Baena-Moreno FM, Malico I, Rodríguez-Galán M, et al. (2020) The importance of governmental incentives for small biomethane plants in South Spain. *Energy* 206: 118158.

Barry F, Sawadogo M, Bologo-Traoré M, et al. (2021) Key barriers to the adoption of biomass gasification in Burkina Faso. *Sustainability* 13: 7324.

Bennici S, Jeguirim M, Limousy L, et al. (2019) Influence of CO_2 concentration and inorganic species on the gasification of lignocellulosic biomass derived chars. *Waste and Biomass Valorization* 10: 3745–3752.

Bocken NMP, de Pauw I, Bakker CA, et al. (2016) Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering* 33:308–320.

Brudermann T, Mitterhuber C and Posch A (2015) Agricultural biogas plants: A systematic analysis of strengths, weaknesses, opportunities and threats. *Energy Policy* 76: 107–111.

Budzianowski WM and Brodacka M (2017) Biomethane storage: Evaluation of technologies, end uses, business models, and sustainability. *Energy Conversion and Management* 141: 254–273.

Chan Gutiérrez E, Wall DM, O'Shea R, et al. (2018) An economic and carbon analysis of biomethane production from food waste to be used as a transport fuel in Mexico. *Journal of Cleaner Production* 196: 852–862.

Chanthawong A and Dhakal S (2016) Stakeholders' perceptions on challenges and opportunities for biodiesel and bioethanol policy development in Thailand. *Energy Policy* 91: 189–206.

Clancy JM, Curtis J and Ó'Gallachóir B (2018) Modelling national policy making to promote bioenergy in heat, transport and electricity to 2030 – Interactions, impacts and conflicts. *Energy Policy* 123: 579–593.

Cremiato R, Mastellone ML, Tagliaferri C, et al. (2018) Environmental impact of municipal solid waste management using Life Cycle Assessment: The effect of anaerobic digestion, materials recovery and secondary fuels production. *Renewable Energy* 124: 180–188.

Cucchiella, D'Adamo I and Gastaldi M (2019) An economic analysis of biogas-biomethane chain from animal residues in Italy. *Journal of Cleaner Production* 230: 888–897.

Daniel-Gromke J, Rensberg N, Denysenko V, et al. (2018) Current Developments in Production and Utilization of Biogas and Biomethane in Germany. *Chemie Ingenieur Technik* 90(1–2): 17–35.

D'Adamo I, Falcone PM, Gastaldi M, et al. (2020) RES-T trajectories and an integrated SWOT-AHP analysis for biomethane. Policy implications to support a green revolution in European transport. *Energy Policy* 138: 111220.

D'Adamo I, Falcone PM, Huisingh D, et al. (2021) A circular economy model based on biomethane: What are the opportunities for the municipality of Rome and beyond? *Renewable Energy* 163: 1660–1672.

D'Adamo I, Gastaldi M, Morone P, et al. (2022) Bioeconomy of sustainability: Drivers, opportunities and policy implications. *Sustainability* 14(1): 200.

European Biogas Association (2022) EBA-GiE biomethane map. Available at: https://www.europeanbiogas.eu/ (accessed 14 March 2022).

European Commission (2018) A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment. *Updated Bioeconomy Strategy*. Available at: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX%3A52018DC0673 (accessed 18 February 2022).

Fedorova E and Pongrácz E (2019) Cumulative social effect assessment framework to evaluate the accumulation of social sustainability benefits of regional bioenergy value chains. *Renewable Energy* 131: 1073–1088.

Ferella F, Puca A, Taglieri G, et al. (2017) Separation of carbon dioxide for biogas upgrading to biomethane. *Journal of Cleaner Production* 164: 1205–1218.

Fernández-González JM, Martín-Pascual J and Zamorano M (2020) Biomethane injection into natural gas network vs composting and biogas production for electricity in Spain: An analysis of key decision factors. *Sustainable Cities and Society* 60: 102242.

Fragoso R, Henriques AC, Ochando-Pulido J, et al. (2021) Enhanced biomethane production by co-digestion of mixed sewage sludge and dephenolised two-phase olive pomace. *Waste Management & Research* 40: 565–574.

Görener A, Toker K and Uluçay K (2012) Application of combined SWOT and AHP: A case study for a manufacturing firm. *Procedia - Social and Behavioral Sciences* 58: 1525–1534.

Gustafsson M, Svensson N, Eklund M, et al. (2021) Well-to-wheel climate performance of gas and electric vehicles in Europe. *Transportation Research Part D: Transport and Environment* 97: 102911.

Haider J, Qyyum MA, Kazmi B, et al. (2020) Simulation study of deep eutectic solvent-based biogas upgrading process integrated with single mixed refrigerant biomethane liquefaction. *Biofuel Research Journal* 7: 1245–1255.

Hao Y, Li W, Tian Z, et al. (2018) Integration of concentrating PVs in anaerobic digestion for biomethane production. *Applied Energy* 231: 80-88.

Herbes C, Chouvellon S and Lacombe J (2018) Towards marketing biomethane in France—French consumers' perception of biomethane. *Energy, Sustainability and Society* 8(1): 1–37.

Hermann BG, Kroeze C and Jawjit W (2007) Assessing environmental performance by combining life cycle assessment, multi-criteria analysis and environmental performance indicators. *Journal of Cleaner Production* 15: 1787–1796.

Hildebrandt J and Bezama A (2018) Cross-fertilisation of ideas for a more sustainable fertiliser market: The need to incubate business concepts for harnessing organic residues and fertilisers on biotechnological conversion platforms in a circular bioeconomy. *Waste Management & Research* 36: 1125–1126.

Horschig T, Welfle A, Billig E, et al. (2019) From Paris agreement to business cases for upgraded biogas: Analysis of potential market uptake for biomethane plants in Germany using biogenic carbon capture and utilization technologies. *Biomass and Bioenergy* 120: 313–323.

Ilicali E and Giritli FH (2020) Measuring the environmental performance of urban regeneration projects using AHP methodology. *A|Z ITU Mimarlık Fakültesi Dergisi* 17: 123–142.

International Energy Agency (2021) Outlook for biogas and biomethane: Prospects for organic growth. Available at: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane (accessed 18 December 2021).

Jackson P, Rivera Ferre MG, Candel J, et al. (2021) Food as a commodity, human right or common good. *Nature Food* 2(3): 132–134.

Jeguirim M, Zorpas AA, Navarro Pedreno J, et al. (2019) 12 - Sustainability assessment for biomass-derived char production and applications. In: Jeguirim M and Limousy L (eds) *Char and Carbon Materials Derived from Biomass*. The Netherlands: Elsevier, pp.447–479.

Kandasamy J and Gökalp I (2015) Pyrolysis, combustion, and steam gasification of various types of scrap tires for energy recovery. *Energy & Fuels* 29: 346–354.

Kardung M, Cingiz K, Costenoble O, et al. (2021) Development of the circular bioeconomy: Drivers and indicators. *Sustainability* 13(1): 413.

Kirchherr J, Reike D and Hekkert M (2017) Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling* 127: 221–232.

Lekkas DF, Panagiotakis I and Dermatas D (2021) A digital circular bioeconomy: Opportunities and challenges for waste management in this new era. *Waste Management & Research* 39: 407–408.

Lindfors A, Feiz R, Eklund M, et al. (2019) Assessing the potential, performance and feasibility of urban solutions: Methodological considerations and learnings from biogas solutions. *Sustainability* 11: 3756.

Loizia P, Voukkali I, Zorpas AA, et al. (2021) Measuring the level of environmental performance in insular areas, through key performed indicators, in the framework of waste strategy development. *Science of the Total Environment* 753: 141974.

Malik K, Rahman SM, Khondaker AN, et al. (2019) Renewable energy utilization to promote sustainability in GCC countries: Policies, drivers, and barriers. *Environmental Science and Pollution Research* 26: 20798–20814.

Moustairas I, Vardopoulos I, Kavouras S, et al. (2022) Exploring factors that affect public acceptance of establishing an urban environmental education and recycling center. *Sustainable Chemistry and Pharmacy* 25: 100605.

Moustakas K, Sotiropoulos D and Vakalis S (2020) Evaluation of the biogas potential of agricultural biomass waste for energy applications in Greece: A case study of the western Greece region. *Waste Management & Research* 39: 438–447.

Ndubuisi-Nnaji UU, Ofon UA and Offiong N-AO (2020) Anaerobic co-digestion of spent coconut copra with cow urine for enhanced biogas production. *Waste Management & Research* 39: 594–600.

Obaideen K, Abdelkareem MA, Wilberforce T, et al. (2022) Biogas role in achievement of the sustainable development goals: Evaluation, challenges, and guidelines. *Journal of the Taiwan Institute of Chemical Engineers* 131: 104207.

Prussi M, Julea A, Lonza L, et al. (2021) Biomethane as alternative fuel for the EU road sector: analysis of existing and planned infrastructure. *Energy Strategy Reviews* 33: 100612.

Ragossnig HA and Ragossnig AM (2021) Biowaste treatment through industrial insect farms: One bioeconomy puzzle piece towards a sustainable net-zero carbon economy? *Waste Management & Research* 39: 1005–1006.

Reißmann D, Thrän D and Bezama A (2018) How to identify suitable ways for the hydrothermal treatment of wet bio-waste? A critical review and methods proposal. *Waste Management & Research* 36: 912–923.

Rocca R, Rosa P, Sassanelli C, et al. (2020) Integrating virtual reality and digital twin in circular economy practices: A laboratory application case. *Sustainability* 12: 2286.

Saaty TL (1980) *The Analytic Process: Planning, Priority Setting, Resources Allocation*. New York, NY: McGraw.

Saaty TL (2008) Decision making with the analytic hierarchy process. *International Journal of Services Sciences* 1(1): 83–98.

Sassanelli C, Rossi M, Pezzotta G, et al. (2019) Defining lean product service systems (PSS) features and research trends through a systematic literature review. *International Journal of Product Lifecycle Management* 12(1): 37–61.

Sassanelli C, Rossi M and Terzi S (2020) Evaluating the smart maturity of manufacturing companies along the product development process to set a PLM project roadmap. *International Journal of Product Lifecycle Management* 12(3): 185–209.

Scarlat N, Fahl F, Dallemand JF, et al. (2018) A spatial analysis of biogas potential from manure in Europe. *Renewable and Sustainable Energy Reviews* 94: 915–930.

Schmid C, Horschig T, Pfeiffer A, et al. (2019) Biogas upgrading: A review of national biomethane strategies and support policies in selected countries. *Energies* 12: 3803.

Sfetsas T, Patsatzis S, Chioti A, et al. (2022) A review of advances in valorization and post-treatment of anaerobic digestion liquid fraction effluent. *Waste Management & Research*. Epub ahead of print 21 January 2022. DOI: 10.1177/0734242X211073000.

Silva I, Jorge C, Brito L, et al. (2020) A pig slurry feast/famine feeding regime strategy to improve mesophilic anaerobic digestion efficiency and digestate hygienisation. *Waste Management & Research* 39: 947–955.

Tapaninaho R and Heikkinen A (2022) Value creation in circular economy business for sustainability: A stakeholder relationship perspective. *Business Strategy and the Environment*. Epub ahead of print 27 January 2022. DOI: 10.1002/bse.3002.

Tomić T and Schneider DR (2018) The role of energy from waste in circular economy and closing the loop concept: Energy analysis approach. *Renewable and Sustainable Energy Reviews* 98: 268–287.

Tsangas M, Jeguirim M, Limousy L, et al. (2019) The application of analytical hierarchy process in combination with PESTEL-SWOT analysis to assess the hydrocarbons sector in cyprus. *Energies* 12: 791.

United Nations (2015) The 17 Goals, Sustainable Development. Available at: https://sdgs.un.org/goals (accessed 18 February 2022).

Vacchi M, Siligardi C, Cedillo-González EI, et al. (2021a) Industry 4.0 and smart data as enablers of the circular economy in manufacturing: Product re-engineering with circular eco-design. *Sustainability* 3:10366.

Vacchi M, Siligardi C, Demaria F, et al. (2021b) Technological sustainability or sustainable technology? A multidimensional vision of sustainability in manufacturing. *Sustainability* 13: 9942.

Valenti F, Porto SMC, Selvaggi R, et al. (2018) Evaluation of biomethane potential from by-products and agricultural residues co-digestion in southern Italy. *Journal of Environmental Management* 223: 834–840.

Vardopoulos I, Tsilika E, Sarantakou E, et al. (2021) An integrated SWOT-PESTLE-AHP model assessing sustainability in adaptive reuse projects. *Applied Sciences* 11: 7134.

Velenturf APM and Purnell P (2021) Principles for a sustainable circular economy. *Sustainable Production and Consumption* 27: 1437–1457.

Veum K and Bauknecht D (2019) How to reach the EU renewables target by 2030? An analysis of the governance framework. *Energy Policy* 127. 299–307.

Voukkali I, Loizia P, Navarro Pedreño J, et al. (2021) Urban strategies evaluation for waste management in coastal areas in the framework of area metabolism. *Waste Management & Research* 39: 448–465.

Voukkali I and Zorpas AA (2021) Evaluation of urban metabolism assessment methods through SWOT analysis and analytical hierocracy process. *Science of the Total Environment* 807(Pt 1): 150700.

WCED (1987) World commission on environment and development. *Our Common Future* 17: 1–91.

Zhu T, Curtis J and Clancy M (2019) Promoting agricultural biogas and biomethane production: Lessons from cross-country studies. *Renewable and Sustainable Energy Reviews* 114: 109332.

Zorpas AA and Saranti A (2016) Multi-criteria analysis of sustainable environmental clean technologies for the treatment of winery's wastewater. *International Journal of Global Environmental Issues* 15: 151–168.

Zorpas AA, Voukkali I and Navarro Pedreño J (2018) Tourist area metabolism and its potential to change through a proposed strategic plan in the framework of sustainable development. *Journal of Cleaner Production* 172: 3609–3620.