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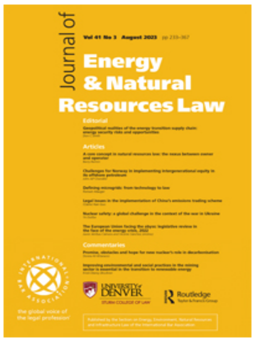

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Defining microgrids: from technology to law

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'Microgrid' is a broad concept that is not determined by a single technical definition. This fact is reflected in the academic literature, which agrees that there is no universal definition of microgrids. While this broad understanding might be beneficial for allowing a broad variety of microgrids, from a legal perspective the absence of a common understanding constitutes a barrier to the development of microgrids. Therefore, this article builds upon an extensive literature review to isolate the most salient characteristics of microgrids and proposes a few key elements that any legal definition of microgrids should include, primarily for the European Union's legal framework, but also applicable to other jurisdictions. It also provides preliminary advice for a legal regime for microgrids that would allow adapting their organisation in terms of ownership and operation to the local context.

Keywords: microgrid; definition; legal framework; energy law; energy transition; law and technology

1. Introduction

After a 20th century dedicated to developing large interconnected electricity networks spanning entire continents, the 21st century sees the concept of microgrids gaining traction. Far from representing a paradigm shift (yet), the emergence of microgrids can actually complement the interconnected network, addressing some of its failures. For instance, microgrids are perceived as a key response to extreme weather events causing blackouts, such as after hurricane Sandy hit New York City in 2012,[1] after hurricane Maria struck Puerto Rico in 2017,[2] after an extreme winter storm caused outages in Texas in early 2021[3] and after each – sometimes preventive – local blackout in California due to wildfires.[4] Aside from this aspect of resilience to climate change consequences, microgrids may facilitate the deployment of distributed renewable energy sources (RESs) by coping with the variability of solar photovoltaic panels and wind turbines at a local level

1 Bobby Magill, 'Microgrids: Sandy Forced Cities to Rethink Power Supply' (*Climate Central*, 9 September 2013) <www.climatecentral.org/news/microgrids-hurricane-sandy-forced-cities-to-rethink-power-supply-16426> accessed 10 February 2022

2 Roy Torbert, 'A Locally Led Move toward Microgrids in Puerto Rico' (*GreenBiz*, 25 September 2019) <www.greenbiz.com/article/locally-led-move-toward-microgrids-puerto-rico> accessed 27 March 2021

3 Tera Roberson, 'Microgrids Offer Alternative Power in Texas' (*Click2Houston*, 10 March 2021) <www.click2houston.com/news/local/2021/03/11/microgrids-offer-alternative-power-in-texas/> accessed 27 March 2021

4 Ken Silverstein, 'California to Fight Wildfires with Microgrids and Batteries' (*Forbes*, 16 June 2020) <www.forbes.com/sites/kensilverstein/2020/06/16/california-energy-regulators-want-to-fight-wildfires-by-facilitating-more-microgrids-and-energy-storage/> accessed 10 February 2022

without congesting the rest of the distribution network or even the transportation network.[5]

The general literature on microgrids agrees on and states repeatedly that there is no universal definition of this concept.[6] In some cases, authors reproduce or combine two or three existing definitions in order to circumvent this issue and provide different approaches to microgrids.[7] The absence of a common technical definition for the concept of a microgrid logically ends up with the absence of a legal definition, although there are some rare examples such as California.[8] This situation constitutes a barrier to the development of microgrids, despite their potential benefits in terms of local resilience, RES expansion,[9] provision of grid services[10] and even to support a democratisation of energy management.[11] Indeed, for the development of a technology – or a set of technologies – legal certainty is essential. Legal certainty can be understood as ensuring predictability, consistency, accessibility and intelligibility of the law.[12] And such legal certainty is especially important in the context of the ongoing energy transition, in the European Union (EU) and elsewhere.[13] In this sense, it can be argued that establishing a legal definition for microgrids is a good start for providing legal certainty, so that stakeholders know what a microgrid is and what it is not.

The aim of this article is to provide a research-based legal definition for microgrids, primarily for the EU, although it could also be adapted to other jurisdictions. The intended geography of adoption matters, given that academic research shows that different geographies lead to the development of microgrids for different reasons. For instance, in the United States of America (US), the first reason for deploying microgrids is resilience against extreme weather events,[14] while in the EU, it is the

5 'What Are Microgrids and How Can They Help in the Energy Transition?' (*IEF*, 29 July 2021) <www.ief.org/news/what-are-microgrids-and-how-can-they-help-in-the-energy-transition> accessed 16 February 2022

6 Mariya Soshinskaya and others, 'Microgrids: Experiences, Barriers and Success Factors' (2014) 40 Renewable and Sustainable Energy Reviews 659, 661; Carmen Wouters, 'Towards a Regulatory Framework for Microgrids – The Singapore Experience' (2015) 15 Sustainable Cities and Society 22, 23; Amjad Ali and others, 'Overview of Current Microgrid Policies, Incentives and Barriers in the European Union, United States and China' (2017) 9(7) Sustainability 1, 1; Adam Hirsch, Yael Parag and Josep Guerrero, 'Microgrids: A Review of Technologies, Key Drivers, and Outstanding Issues' (2018) 90 Renewable and Sustainable Energy Reviews 402, 403

7 See Soshinskaya and others (n 6) 661; Ali and others (n 6) 1

8 See section 6 below

9 Stefano Bifaretti and others, 'Grid-Connected Microgrids to Support Renewable Energy Sources Penetration' (2017) 105 Energy Procedia 2910

10 T&D Europe, 'Harnessing Microgrid Technology Opportunities – To Lead The Energy Transition in Europe' (2019) 1, 6 <https://gimelec.fr/wp-content/uploads/2019/05/TDEurope-brochure_microgrids_web-min.pdf> accessed 16 February 2022

11 Jessica Wentz and Chiara Pappalardo, 'Scaling up Local Solutions: Creating an Enabling Legal Environment for the Deployment of Community-Based Renewable Microgrids' in Jordi Jaria i Manzano, Nathalie Chalifour and Louis J Kotzé (eds) *Energy, Governance and Sustainability* (Edward Elgar 2016) 99, 105

12 Mark Fenwick, Mathias Siems and Stefan Wrbka, 'The State of the Art and Shifting Meaning of Legal Certainty' in Mark Fenwick, Mathias Siems and Stefan Wrbka (eds) *The Shifting Meaning of Legal Certainty in Comparative and Transnational Law* (Hart 2017) 1, 6–7

13 Kaisa Huhta, 'Anchoring the Energy Transition with Legal Certainty in EU law' (2020) 2(4) Maastricht Journal of European and Comparative Law 425, 427

14 Kevin B Jones, Mark James and Roxana-Andreea Mastor, 'Securing Our Energy Future: Three International Perspectives on Microgrids and Distributed Renewables as a Path Toward Resilient Communities' (2016) 16(2) Environmental Hazards 1, 3; Warda Ajaz, 'Resilience, Environmental Concern, or

decarbonisation of the energy system.[15] Bearing these differences in mind, sources from a diversity of geographies are used in this research to come up with a potential legal definition. I see two main reasons for targeting the EU: firstly, this research was funded by a European grant and therefore focused from the start on the situation in the EU.[16] Secondly, as mentioned by Jones, James and Mastor, despite the absence of a legal definition for microgrids, 'EU energy and climate policy is favorable toward microgrid implementation'.[17] I believe that adopting a legal definition for microgrids can only further facilitate the development of microgrids in the EU.

To reach a working legal definition, it is necessary to understand what microgrids are in a technical sense. Without such an understanding, it is not possible to discuss how best to regulate microgrids. This proximity between technology and law is actually a trademark of energy law. This is hinted at by Heffron and Talus when they refer to the contribution of 'advances in technology' to the change in energy law,[18] and it is elaborated upon by Hutha's 'energy law's problem-based approach'[19] and the impossibility for this discipline to 'be severed from the physical, economic, and social preconditions that determine how law functions'.[20] That is also why in practice, a legal definition for microgrids cannot be based solely on technical elements. From the moment it is being adopted by a legislator, it is the result of a political compromise, therefore also integrating economic, social, environmental, cultural and other such considerations. Therefore, the definition elaborated in this article takes into account the EU's above-mentioned main goal when it comes to microgrids: decarbonisation.

This article builds upon an extensive literature review of microgrids and their definitions. To start with, a word search was carried on Google, Google Scholar, SmartCat (the University of Groningen's Library search tool) and ProQuest using combinations of the terms 'microgrids', 'definition' and 'legal'. In total, over 30 relevant scientific articles, academic book chapters, policy documents and official reports were reviewed and used for this research, the vast majority of which were published between 2010 and 2020. Of these works, 17 included what they clearly considered to be a definition of microgrids and were therefore chosen to build up a common technical definition of microgrids. Most of the selected documents are peer-reviewed academic articles (13 out of 17), followed by academic book chapters (three out of 17) and a single report by the European Commission. This research was realised over a period spanning from the summer of 2020 to early 2021. It should be noted that it was undertaken in parallel with the research realised by Behrendt on the same topic and at the same

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Energy Democracy? A Panel Data Analysis of Microgrid Adoption in the United States' (2019) 49 Energy Research & Social Science 26, 31; Martin Warneryd, Maria Håkansson and Kersti Karltorp, 'Unpacking the Complexity of Community Microgrids: A Review of Institutions' Roles for Development of Microgrids' (2020) 121 Renewable and Sustainable Energy Reviews 1, 5

15 Jones, James and Mastor (n 14) 10

16 SMart IsLand Energy systems (SMILE) project, Horizon2020 research programme, grant agreement no. 731249, results available at <https://cordis.europa.eu/project/id/731249> accessed 26 October 2022

17 Jones, James and Mastor (n 14) 11

18 Raphael J Heffron and Kim Talus, 'The Development of Energy Law in the 21st Century: A Paradigm Shift?' (2016) 9 Journal of World Energy Law and Business 189, 197

19 Kaisa Huhta, 'The Coming of Age of Energy Jurisprudence' (2021) 39(2) Journal of Energy & Natural Resources Law 199, 204

20 Kaisa Huhta, 'The Contribution of Energy Law to The Energy Transition and Energy Research' (2022) 73 Global Environmental Change 1, 2

research centre. Her research was published after this study's data gathering period ended and is therefore not included in the literature review.[21] Academically, this parallel development allows us to perceive the different results that can be reached on a similar topic with two different methods.

Each section of this article builds upon the previous one. Section 2 contains a detailed analysis of the existing technical definitions for microgrids, based on the literature review. It allows the identification of the main components for a universal conceptualisation of microgrids. Section 3 differentiates microgrids from other notions with which they are often confused. Section 4 dives into the various types of microgrids that actually exist within the common notion. Section 5 outlines the different types of microgrid management systems that exist. Finally, section 6 comes to a conclusion and proposes a legal definition as well as preliminary advice for a legal regime adapted to the development of microgrids, especially fit for – but not limited to – the EU.

2. Analysing existing microgrid definitions

The 17 selected documents mentioned in the introduction have been organised in Table 1.[22] In this table, each definition is analysed and its components separated and distributed within 13 columns, each representing a specific attribute or capacity characterising microgrids. The selection of these elements represents the full range of those actually present in the 17 documents that were isolated.

21 Jamie Behrendt, 'Small Systems: Big Impacts – Examining the Concept of Microgrids from an EU Law Perspective' (2021) 30(3) European Energy and Environmental Law Review 74

22 Robert H Lasseter, 'MicroGrids' (2002) 1 IEEE Power Engineering Society Winter Meeting 305, 305; European Commission, 'European SmartGrids Technology Platform: Vision and Strategy for Europe's Electricity Networks of the Future' (2006) 27; Nilakshi WA Lidula and Athula D Rajapakse, 'Microgrids Research: A Review of Experimental Microgrids and Test Systems' (2011) 15 Renewable and Sustainable Energy Reviews 186, 186; Gregory J Kish and Peter W Lehn, 'Microgrid Design Considerations for Next Generation Grid Codes' (2012) IEEE Power and Energy Society General Meeting 1, 1; John Romankiewicz and others, 'Lessons from International Experience for China's Microgrid Demonstration Program' (2014) 67 Energy Policy 198, 199; José F Sanz and others, 'Analysis of European Policies and Incentives for Microgrids' (2014) Proceedings of the International Conference on Renewable Energies and Power Quality, Cordoba, Spain 874, 874; Christine Schwaegerl and Liang Tao, 'The Microgrids Concept' in Nikos Hatziargyriou (ed) *Microgrid: architectures and Control* (IEEE Press, 2014) 1, 1; Soshinskaya and others (n 6) 660; Wouters (n 6) 23; Lexuan Meng and others, 'Microgrid Supervisory Controllers and Energy Management Systems: A Literature Review' (2016) 60 Renewable and Sustainable Energy Reviews 1263, 1264; Abdorreza Rabiee and others, 'Optimal Operation of Microgrids through Simultaneous Scheduling of Electrical Vehicles and Responsive Loads Considering Wind and PV Units Uncertainties' (2016) 57 Renewable and Sustainable Energy Reviews 721, 722; Ali and others (n 6) 1–2; Yeliz Yoldaş and others, 'Enhancing Smart Grid with Microgrids: Challenges and Opportunities' (2017) 72 Renewable and Sustainable Energy Reviews 205, 205; Yimy E García Vera, Rodolfo Dufo-López and José L Bernal-Agustín, 'Energy Management in Microgrids with Renewable Energy Sources: A Literature Review' (2019) 9 Applied Sciences 1, 2; Michiel A Heldeweg and Imke Lammers, 'An Empirico-Legal Analytical and Design Model for Local Microgrids: Applying the 'ILTIAD' Model, Combining the IAD-Framework with Institutional Legal Theory' (2019) 13(1) International Journal of the Commons 479, 480–82; Naser Mahdavi Tabatabaei, Ersan Kabalci and Nicu Bizon, 'Overview of Microgrid' in Naser Mahdavi Tabatabaei, Ersan Kabalci and Nicu Bizon (eds) *Microgrid Architectures, Control and Protection Methods* (Springer 2020) 1, 4; Donna Attanasio, 'Microgrids' in Martha Roggenkamp, Kars De Graaf and Ruven Fleming (eds) *Elgar Encyclopedia of Environmental Law Series: Energy Law, Climate Change and the Environment* (Edward Elgar 2021) 656, 656–657

Table 1. Analysis of the attributes and characteristics of microgrids in 17 definitions. Source: author's elaboration.

Source	Elec-tricity	Heat	Low-/medium-voltage grid	Single entity	Controllable sources/loads	Generation: Renewable Energy Sources	Generation: conventional	Storage	Island-ing	Isolated	Relia-bility	Services to distrib. grid	Local area
Lasseter (2002)	X	X		X									X
European Commission (2006)	X		X	X	X			X	X			X	
Lidula, Rajapakse (2011)	X		X					X	X		X		
Kish, Lehn (2012)	X		X						X				X
Romankie-wicz and others (2014)	X			X	X			X	X			X	
Sanz and others (2014)	X		X		X			X	X				
Schwaegerl, Tao (2014)	X		X		X	X	X	X	X			X	
Soshinskaya and others (2014)	X		X		X	X	X	X	X				X
Wouters (2015)	X		X	X	X			X	X				X
Meng and others (2016)	X		X			X	X	X	X		X		

(*Continued*)

Table 1. Continued.

Source	Electricity	Heat	Low-/medium-voltage grid	Single entity	Controllable sources/loads	Generation: Renewable Energy Sources	Generation: conventional	Storage	Islanding	Isolated	Reliability	Services to distrib. grid	Local area
Rabiee and others (2016)	X		X		X			X		X			
Ali and others (2017)									X	X	X		
Yoldaş and others (2017)	X				X	X	X	X	X		X		X
García Vera, Dufo-López, Bernal-Agustín (2019)	X		X		X	X	X	X	X		X		
Heldeweg, Lammers (2019)	X		X						X				X
Mahdavi Tabatabaei, Kabalci, Bizon (2020)	X		X						X				
Attanasio (2021)	X	X	X							X			
Total mentions (out of 17)	16	2	13	4	9	5	5	11	14	3	5	3	6

The 13 columns assess whether each definition includes electricity and/or heat, whether it forms or is part of a low- or medium-voltage grid, whether it represents a single entity (towards the connecting distribution grid operator), whether it contains controllable sources or loads (where load is understood as energy consumption), whether it includes generation from RESs and/or conventional generation, whether it integrates storage, whether it can switch to islanded mode, whether it comprises isolated systems (not connected to the main grid at all), whether it increases reliability, whether it can provide services to the connecting distribution grid, and finally, whether it is explicitly aimed at acting at a local level. As each definition is different, it is sometimes a matter of interpretation or deduction to consider that a requirement is fulfilled. Also, it is assumed that the definitions include both energy sources and loads, as, even if not mentioned, none of the other activities can be undertaken without them. It should be noted that a number of definitions mention some specific notions, but these were either too close to other notions already present in the table, such as distributed energy resources,[23] too general, such as consumers, customers or end users,[24] or too anecdotal, such as smart buildings.[25]

The results of this analysis are manifold. First, the smallest common denominator among the definitions of microgrids is: an electricity grid capable of islanding from the public grid, meaning to temporarily disconnect from the public grid and operate in isolation before reconnecting to it. Second, energy storage and controllable sources and loads appear in at least half of the definitions, underlining the fact that although they are not compulsory, their addition to a microgrid is often deemed very useful. Indeed, these technologies allow for the balancing of supply and demand inside a grid, and the smaller the grid, the more necessary these tools are, especially if the microgrid includes high shares of variable RESs. Third, various definitions noticeably emphasise the notion of localness, as a microgrid often has a limited geographical scope. Sometimes definitions specify that a microgrid is a ‘small-scale’ grid,[26] which is therefore local by nature. Fourth, each time a definition includes the type of energy sources that can be used in a microgrid, it either explicitly mentions both RESs and conventional (or traditional) sources, or it lists some options that always include RESs and conventional sources. This shows that although microgrids are often presented as an option to develop local 100 per cent RES-powered grids and to raise the penetration rate of these sources in the national energy mix, definitions are actually energy-source neutral. Fifth, the reliability of the electricity supply also appears in various definitions, rather logically at the same level as the type of energy source, as the motivation for microgrid development is usually either RES development, improved supply reliability or a combination of both. Sixth, the fact that the microgrid is considered a single entity for the connecting distribution grid operator does not appear much. This shows that this is either self-evident or perhaps not very important in the eyes of the authors. However, this can be tied to the management choice of the microgrid and can have important legal consequences, as is explored further below in section

23 Kish and Lehn (n 22) 1; Ali and others (n 6) 1; Attanasio (n 22) 656

24 Schwaegerl and Tao (n 22) 1; García Vera, Dufo-López and Bernal-Agustín (n 22) 2; Attanasio (n 22) 656

25 Schwaegerl and Tao (n 22) 1

26 Soshinskaya and others (n 6) 660; Meng and others (n 22) 1264

5. Seventh, the possibility of considering an isolated system to be a microgrid is equally common and certainly indicates that microgrids are in most cases considered to be interconnected grids, which can temporarily be islanded but are not permanently so. Eighth, the option to provide services to the connecting distribution grid is only mentioned in two sources, while this is actually a very important feature of modern microgrids, especially to ensure profitability or at least to recoup (part of) the realised investments.[27] Ninth, heat appears only twice, which highlights that microgrids are first and foremost about electricity. Nevertheless, electricity and heat will be increasingly interlinked in the future[28] and EU law already requires distribution system operators (DSOs) to consider using 'district heating or cooling systems to provide balancing and other system services'.[29]

As a final outcome of this table, this time focusing on the rows and therefore comparing the different definitions, it appears that while some definitions are very detailed and include technical elements on generation, control, storage and so on, others are much more restrictive and constructed based on only a few key elements. However, there is no causal relationship between the length or exhaustiveness of a definition and its quality (or vice versa), as a definition can be too long, too vague, too broad or too technical, especially for use in a legal framework.

In a nutshell, the core elements for a definition of microgrids based on the literature review are: an islanding-capable grid, using flexible technologies to remain balanced and forming a local and rather small-scale network.

Yet it must be noted that there is one definition that is often used in academic literature and that actually appears in a few of the 17 sources analysed in Table 1. This definition comes from the Microgrid Exchange Group and has been adopted by the US Department of Energy (DoE).[30] It reads as follows:

> [A microgrid is] a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.

This definition covers three criteria: a group of interconnected loads and generation, clearly defined boundaries materialising through a single connection point to the main grid, and the islanding capacity (here expressed as the capacity to disconnect and reconnect from the (public) grid). According to Attanasio,[31] this definition or a variant of it is often used in regulation in the US, such as by the state of Connecticut[32]

27 Schwaegerl and Tao (n 22) 15; T&D Europe (n 10) 6
28 See for instance European Commission, 'Powering a Climate-Neutral Economy: An EU Strategy for Energy System Integration' (Communication) COM (2020) 299 final
29 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources [2018] OJ L328, art 24 (8)
30 Romankiewicz (n 22) 199; Klemens Leutgöb and others, 'New Business Models Enabling Higher Flexibility on Energy Markets' (2019) ECEEE Summer Study Proceedings 235, 243; Hirsch, Parag and Guerrero (n 6) 403; Warneryd, Håkansson and Karltorp (n 14), 2
31 Attanasio (n 22) 657
32 Connecticut General Statutes s 16-243y a (5) (2018) <https://law.justia.com/codes/connecticut/2018/title-16/chapter-283/section-16-243y/> accessed 10 February 2022

or on the island of Puerto Rico.[33] Indeed, although fairly short, this definition contains two of the three identified essential elements. The only aspect that could be added is the emphasis on energy storage and controllable sources.

3. Differentiating microgrids from other concepts

It is important to differentiate the category 'microgrids' from other terms and concepts with which it is often conflated or confused. Indeed, microgrids must be distinguished from smart grids, mini-grids, active distribution networks (ADNs) and energy communities, to name some of these related terms and concepts stemming from the international technical literature (and not necessarily referring to legally defined notions). This is represented in Figure 1.

Firstly, a smart grid can be defined as:

> an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that assume both roles – in order to efficiently deliver sustainable, economic and secure electricity supplies. A smart grid employs innovative products and services together with intelligent monitoring, control, communication and self-healing technologies.[34]

There is a close relationship between microgrids and smart grids. However, smart grids take place at a higher network level (including transmission and distribution) and on a broader geographical scale.[35] Yet it should be noted that modern microgrids, which run entirely on variable RESs (or are progressively reaching this target), need to be smart. Indeed, in order to constantly balance electricity production and demand, intelligent monitoring and control of production, storage and consumption assets is key.[36] In sum, in the future, the vast majority of microgrids will be smart grids, but not all smart grids will be microgrids.

Secondly, according to the International Renewable Energy Agency (IRENA), a mini-grid is an 'integrated energy infrastructure, based on distributed power-generation […]. Although normally autonomous, these can also connect to the main grid'.[37] In general, the term mini-grid is used for 'remote and island communities', especially those that are burgeoning in developing countries in order to provide electricity access in rural areas.[38] The main confusion between microgrids and mini-grids comes from the fact that (1) both systems are generally small in geographical size and installed capacity, and (2) sometimes isolated grids are qualified as microgrids (although they are not the same). To clarify, in principle, microgrids are

33 Energy Bureau of the Puerto Rico Public Service, Regulation on Microgrid Development (Order 9028) s 1.08(20)

34 Schwaegerl and Tao (n 22) 1

35 Yoldaş and others (n 22) 206; Attanasio (n 22) 657; Lidula and Rajapakse (n 22) 201

36 García Vera, Dufo-López and Bernal-Agustín (n 22) 2; Wouters (n 6) 23

37 IRENA 'Innovation Landscape Brief: Renewable Mini-Grids' (2019) 1, 3 <www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Renewable_mini-grids_2019.pdf?la=en&hash=CFE9676B470A96F7A974CB619889F5810A06043E> accessed 16 February 2021

38 MGP, Bloomberg NEF and Se4All, 'State of the Global Mini-Grids Market Report 2020) 1, 4 <https://minigrids.org/wp-content/uploads/2020/06/Mini-grids_Market_Report-20.pdf> accessed 10 February 2022

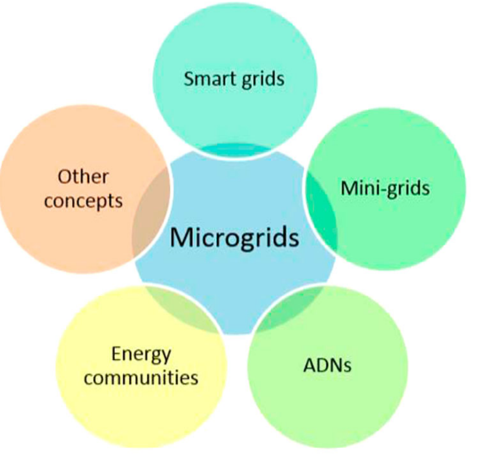

Figure 1. Representation of the interrelationship between microgrids and similar concepts and terms.
Source: author's elaboration.

grid-connected but can island and reconnect at will, while mini-grids are either interconnected to the main grid or isolated from it but do not have islanding capacity.

Thirdly, an ADN is a distributed network that is able to 'control a combination of distributed energy resources (generators, loads and storage). DSOs have the possibility of managing the electricity flows using a flexible network topology'.[39] To differentiate them from microgrids, Soshinskaya argues that 'fully grid-tied system[s] with distributed generation that cannot operate in island mode are not microgrids, but instead can be defined as active distribution networks'.[40] The dividing line between microgrids and ADNs thus again lies in the islanding capacity of the former, while the latter is a smartened classic distribution network.

Fourthly, microgrids may sometimes be conflated with energy communities. Energy communities usually qualify the collective organisation of small energy actors (small-sized final (active) consumers, producers and/or energy storage operators), often tied together by local proximity and not driven by a financial profit purpose but rather by the goal of making local environmental, social and economic improvements. Energy communities are not the material set-up of a network; instead, they constitute an entity that can own and operate such grid, which then can take the shape of a microgrid if it can island.[41]

In sum, the key distinguishing feature of the microgrid is its islanding capacity. This is the main quality that makes it stand out from other smart grid or small grid concepts.

39 Christian D'Adamo, Samuel Jupe and Chad Abbey, 'Global Survey on Planning and Operation of Active Distribution Networks – Update of CIGRE C6.11 Working Group Activities [C]//Electricity Distribution-Part 1', 20th International Conference on Electricity Distribution (2009) 1, 1

40 Soshinskaya and others (n 6) 661

41 As requested by the EU energy communities' advocacy organisation: Rescoop.eu, 'What Local Energy Communities Need from the Clean Energy Packaged' undated 1, 7

4. Different types of microgrids

Once the concept of microgrid is clearly delimited and separated from other concepts, it is necessary to identify the different types of microgrids within this category. In this regard, the literature proceeds with varying criteria. For instance, for Attanasio, '[m]icrogrids vary in size, purpose, capabilities, and the composition of loads and resources'.[42] Below, I assess the classification of microgrids based on their size and purpose, and their centralised or decentralised character.

4.1. *Microgrids and the issue of size*

Many authors qualify microgrids as 'small' grids, as mentioned in section 2. Indeed, the very name 'microgrids' implies that these grids are small in size. However, what does size refer to in this case? Is it about geographical extension? About the installed energy production capacity? About the number of connected customers?

Soshinskaya and others argue that 'there is no universally accepted minimum or maximum size' and deduce that microgrids are not defined by their size.[43] Indeed, using a geographical extension criterion would be arbitrary, especially since distances are relative between urban and rural contexts. In addition, a geographical extension criterion for microgrids would risk creating lengthy debates and would certainly legally result in one that is not adapted to the diversity of situations in EU countries. On the contrary, the same authors write that the 'size of a microgrid depends basically on the peak power required by the loads' and that 'most real-world microgrids are typically in the MW scale range'.[44] Such an installed-capacity size criterion may be an option, given that it is already used in EU law for some cases, such as for the application of support scheme guidelines,[45] of third-party access to district heating and cooling systems for renewable energy production,[46] or of the sustainability and greenhouse gas emissions saving criteria for electricity production from biomass.[47]

The third use of the notion of size to be tackled is the number of connected customers. Here as well, the difference in density between urban and rural contexts may raise some difficulties. However, this criterion is already used in EU law, especially to distinguish between fewer than and more than 100 000 connected customers for the applicable distribution network management regime.[48] This can have fundamental consequences, as detailed below in section 5. However, no microgrids in the EU are expected to gather more than 100,000 connected customers each, at least for the foreseeable future, which implies that they can potentially all benefit from the exception regime granted by this situation, if transposed as such in national law. Therefore, this is more of a common legal feature of microgrids rather than a criterion to differentiate between them.

42 Attanasio (n 22) 657
43 Soshinskaya and others (n 6) 661
44 *Ibid* 661 and 663
45 2018 Renewable Energy Sources Directive (n 29) recital 19
46 *Ibid* art 24 (6) (d)
47 *Ibid* art 29 (11)
48 Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU [2019] OJ L 158, art 35 (4)

Raising the question of size implies raising the question of the limit. Where do we place the border between the microgrid and the public distribution grid? The literature generally considers that this limit is set at the point of common coupling (PCC) between the two grids.[49] The notion of a PCC is comparable to the connection point in EU law.[50] This is where the islanding and reconnection take place. According to Lidula and Rajapakse, the PCC 'lies at the vicinity of the low voltage side of the substation transformer'.[51] But one could also imagine that a substation transformer is itself the PCC, especially if the microgrid is in the MW range. The option of creating multi-microgrids, as the literature proposes (essentially, a group of microgrids connected to the same section of the public network and which can act in a coordinated manner),[52] opens new perspectives regarding the PCC and the microgrid's size. Indeed, what about a neural system where a full branch of the distribution grid behind a substation is composed of various microgrids that could be operated separately or together? Where is the PCC located then – at the substation itself or farther down the line? How is the installed capacity or the number of connected customers to be counted? In a multi-microgrid scenario, the classic orders of magnitude of microgrids could be surpassed and may spur the need for different legal regimes within the microgrid category itself. In all these cases, from the existing ones to the potential future developments, one of the main legal questions to be asked is: who controls the PCC?

4.2. *Microgrids with a diversity of purposes*

It is possible to classify microgrids into five categories based on their purpose. Mahdavi Tabatabaei, Kabalci and Bizon mention commercial, community, campus, military and remote microgrids.[53] Commercial and industrial microgrids generally operate grid-connected and their purpose is to save costs and provide a backup in case of grid issues. According to these authors, community microgrids target enhanced grid stability, but one might rather consider them as microgrids created by energy communities, with the corresponding motivations, as mentioned in section 3. Campus microgrids, developed by institutions such as universities and hospitals, require uninterruptible power for their research activities or medical emergencies. Military microgrids have a security purpose (eg avoiding power cut threats). Some of these microgrids can actually operate isolated from the public grid: the aforementioned remote microgrids. However, in this case, this reopens the debate about the importance of the 'grid-connected with islanding capacity' criterion and blurs the lines with other concepts. As noted by Warneryd, Håkansson and Karltorp,[54] some physically isolated grids have historically been labelled 'microgrids', but the use of the term in these cases

49 Mahdavi Tabatabaei, Kabalci and Bizon (n 22) 4; Soshinskaya and others (n 6) 667
50 See for instance Commission Regulation (EU) 2016/631 of 14 April 2016 Establishing a Network Code on Requirements for Grid Connection of Generators [2016] OJ L 112, art 2 (15)
51 Lidula and Rajapakse (n 22) 187
52 Hirsch, Parag and Guerrero (n 6) 408; Schwaegerl and Tao (n 22) 4 and 6; João Abel Peças Lopes and others, 'Operation of Multi-Microgrids' in Nikos Hatziargyriou (ed) *Microgrid: Architectures and Control* (IEEE 2014) 165
53 Mahdavi Tabatabaei, Kabalci and Bizon (n 22) 4
54 Warneryd, Håkansson and Karltorp (n 14) 2

should be prohibited as it only creates confusion for the legal framework to be developed. It should be noted that it might not be useful to create different legal regimes for these different categories of microgrids. Indeed, commercial, community and campus microgrids will most likely have the same rights and duties, and their owners or operators may decide to leverage their potential differently according to their needs.

4.3. *Microgrids' dividing line: centralised or decentralised?*

The technical literature often distinguishes between centralised and decentralised microgrids.[55] Indeed, microgrids need an operator in order to stay balanced and avoid black-outs. This is especially important when the microgrid is islanded (from the moment of disconnection to the reconnection and re-synchronisation with the main grid). It should be noted that the literature also sometimes refers to 'fully decentralised control' versus 'hierarchical control' of the microgrid.[56]

In a centralised energy management system for a microgrid, the microgrid central controller (MGCC) manages the internal balancing of the system. To do so, it relies on extensive two-way communication tools, as it needs to monitor and control each unit (production, consumption or storage) in the system.[57] This type of control system is 'very suitable for small scale' microgrids[58] and when such systems have a single owner.[59] It then allows for profit maximisation. However, it also has a significant weakness due to its centrality: if the MGCC fails, then the whole microgrid might collapse. It is argued to have 'low reliability and redundancy',[60] it needs 'more computing infrastructure [which] will result in an overload of the Microgrid central control system', and it is very difficult to implement for geographically extended large microgrids.[61]

Conversely, in a decentralised energy management system for a microgrid, local controllers (LCs) are the main actors in what is called a multi-agent system (MAS). They provide their energy services (production, consumption or storage) in a competitive manner to an internal market setting.[62] There is still a central controller (or MGCC), but with a more limited role, essentially negotiating with the LCs to obtain the necessary grid services and taking care of grid transactions with the connecting DSO.[63] This system's architecture is more resilient than the centralised one because it can continue 'normal operation even after loss of [MGCC] functions'.[64] It is suitable

55 Hirsch, Parag and Guerrero (n 6) 404; García Vera, Dufo-López and Bernal-Agustín (n 22) 21

56 Aris Dimeas and others, 'Deliverable DB1, TB1. Requirements Specifications for Microgrid Control' (EU project MORE MICROGRIDS – Advanced Architectures and Control Concepts for More Microgrids, July 2006), 1, 5

57 Yoldaş and others (n 22) 210; Ahmet Karaarslan and M Emrah Seker, 'Distributed Control of Microgrids' in Naser Mahdavi Tabatabaei and Ersan Kabalci (eds) *Microgrid Architectures, Control and Protection Methods* (Springer 2020) 403, 418

58 Yoldaş and others (n 22) 210

59 Farid Hamzeh Aghdam and Navid Taghizadegan Kalantari, 'Energy Management Requirements for Microgrids' in Naser Mahdavi Tabatabaei and Ersan Kabalci (eds) *Microgrid Architectures, Control and Protection Methods* (Springer 2020) 233, 235

60 Yoldaş and others (n 22) 210

61 Karaarslan and Seker (n 57) 418

62 Hamzeh Aghdam and Taghizadegan Kalantari (n 59) 235; Dimeas (n 56) 5

63 Hamzeh Aghdam and Taghizadegan Kalantari (n 59) 235

64 Meng and others (n 22) 1266

for large microgrids, with many resources owned by a variety of actors.[65] According to Mattioli and Shackelford, microgrids would 'intuitively' opt for 'a decentralized metering and payment system', using blockchain in their case.[66] However, this system is not free from weaknesses, as it requires a high level of synchronisation between the LC units and between them and the MGCC due to their interdependence.[67] Additionally, it is based on the willingness of each actor to maximise its profits, potentially creating conflicts.[68]

The centralised and decentralised microgrid architectures reflect the two main models for electricity system management. On the one hand, there is the vertically integrated operator model, corresponding for instance to the pre-2000s model in the EU and referred to as 'vertically integrated undertaking' (VIU) in EU law.[69] This model is more centralised and relies on a single actor who owns and operates the grid as well as production and supply. On the other hand, the market-based model corresponds, for instance, to the current liberalised structure in the EU and is more decentralised in the sense that it includes more actors competing against each other, with – in the middle – an independent grid operator responsible for maintaining the grid's balance by mobilising in priority the (most competitive) voluntary market actors. In this sense, microgrids and their two main market models reproduce these two governance choices on a small scale. Indeed, the choice of a centralised or decentralised microgrid, based on local technical, economic, cultural and social elements, is not neutral and will have an impact on the applicable legal regime and the microgrid's actors. The following section discusses these internal architecture alternatives and their potential legal consequences.

5. Different types of microgrid management systems

Schwaegerl and Tao propose three typical set-ups for microgrid management systems: DSO monopoly, free-market and prosumer consortium models.[70] However, these can also be grouped under centralised and decentralised microgrids, as in the previous section. The term of 'DSO monopoly' corresponds to a centralised system operated by a VIU. Conversely, a decentralised system tends to be operated as a liberalised, market-based system with an independent DSO. Within this decentralised system, the classic form is the free market and the one emerging following technical developments is the prosumer consortium.

The VIU microgrid is operated by a bundled entity that may own and certainly operates the generation, distribution, supply and storage of energy. The role of the other microgrid participants (consumers, potential producers, suppliers and flexibility providers) is very limited, but consumers may be incentivised by dynamic pricing schemes. It might also be possible, to some extent, for so-called prosumers or

65 Hamzeh Aghdam and Taghizadegan Kalantari (n 59) 235

66 Michael Mattioli and Scott J Shackelford, 'Powerhouses: A Comparative Analysis of Blockchain-Enabled Smart Microgrids' (2021), 46(4) The Journal of Corporation Law, 1003, 1006

67 Meng and others (n 22) 1266

68 Hamzeh Aghdam and Taghizadegan Kalantari (n 59) 235; García Vera, Dufo-López and Bernal-Agustín (n 23) 21

69 2019 Electricity Market Directive (n 48) art 2 (53)

70 Schwaegerl and Tao (n 22) 16–18

active customers[71] to sell flexibility services to the VIU, but this will differ on a case-by-case basis. Legally, VIUs are prohibited in the EU, save for systems with fewer than 100 000 connected customers,[72] which is a size microgrids should not reach in the foreseeable future, at least in EU countries, as explained previously in section 4.1. Such a VIU may be independent, or owned by another larger DSO. In that case, the question arises whether this monopoly regime is possible if the microgrid's VIU is owned by an unbundled DSO, especially when the microgrid is in grid-connected mode and therefore part of the public grid. Another option is that the VIU is actually owned by an energy community. The 2019 Electricity market Directive allows the Citizen Energy Communities (CECs) in the EU to own grids and thus potentially become small local VIUs.[73] However, this directive's provision is optional, and member states may decide not to transpose it into their national law, as was decided in several countries including France[74] and Denmark.[75]

The free-market model is essentially a small-scale reproduction of the liberalised electricity market in the EU.[76] In this system the DSO is unbundled and cannot undertake any generation, storage or supply activities. Therefore, in the case of a microgrid, there is one DSO and one or more energy producers, suppliers and storage operators. This system is usually technically run as a decentralised microgrid, with plenty of actors undertaking each activity, and still with an MGCC but with a limited role: 'monitoring for system security and upper grid transactions'.[77] Such a microgrid is organised around a local energy and flexibility market where each actor tries to maximise its benefits. A free-market system could also be centralised to an extent, or settled as a hybrid between centralised and decentralised, for example if one actor owns the majority of the generation, storage and supply activities. This actor could be a classic private company, but it could also be a CEC.

The prosumer consortium naturally tends to be decentralised too (although it can also apply to a hybrid form of microgrid). This system relies on active customers as defined by the 2019 Electricity Market Directive or (jointly acting) renewables self-consumers as defined by the 2018 Renewable Energy Sources Directive.[78] In this MAS, prosumers organise themselves to set their own rules for energy production, supply and storage, as well as for flexibility services that rely on demand response. Each of them owns and operates its equipment under these rules and they control the MGCC together. There is still an unbundled DSO, applying grid stability rules.

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71 'Active customers' is the term used in EU law; see 2019 Electricity market Directive (n 48) art 2 (8)

72 2019 Electricity Market Directive (n 48) art 35 (4)

73 *Ibid* art 16

74 *Ordonnance n° 2021-236 du 3 mars 2021 portant transposition de diverses dispositions de la directive (UE) 2018/2001 du Parlement européen et du Conseil du 11 décembre 2018 relative à la promotion de l'utilisation de l'énergie produite à partir de sources renouvelables et de la directive (UE) 2019/944 du Parlement européen et du Conseil du 5 juin 2019 concernant des règles communes pour le marché intérieur de l'électricité*, art 5

75 *Bekendtgørelse om borgerenergifællesskaber og forholdet mellem borgerenergifællesskaber og elhandelsvirksomheder og kollektive elforsyningsvirksomheder*, 2252, 29/12/2020, art 5

76 For more, see Hans Vedder and others, 'EU Energy Law' in Martha M Roggenkamp (eds) *Energy Law in Europe: National, EU and International Regulation* (3rd edn, OUP 2016) 187, 264ff

77 Hamzeh Aghdam and Taghizadegan Kalantari (n 59) 236

78 2019 Electricity Market Directive (n 48) art 15; and 2018 Renewable Energy Sources Directive (n 29) art 21

This DSO has to be autonomous from the consortium (at least legally, in the EU);[79] otherwise, the microgrid becomes a prosumer-owned and -operated VIU.

Interestingly enough, Soshinskaya wrote in 2014 that for microgrids 'the most common models in the EU are DSO Monopolies compared to more Free Market and Prosumer models around the world'.[80] This is a particularly paradoxical situation, given that the EU implemented a liberalised electricity market while many non-EU countries did not. However, this situation might have changed since then. In any case, this statement raises the question of the acceptability of a bundled grid located within an unbundled electricity market. This is one of the main recurring questions regarding microgrids according to Attanasio,[81] and it justifies the need for a legal exemption for Wouters.[82]

6. Conclusion: elements for a legal definition and preliminary advice for a legal regime

Technical and legal definitions sometimes differ. Indeed, technical definitions, albeit close to reality, may prove too complex to be intelligible to all and to be efficiently applied by the courts. That is why when a legal definition for a technical concept is needed, a specific reflection is mandatory, and microgrids are no exception. However, the literature on the legal aspects of microgrids is limited, and the few existing publications focus largely on the lack of legal certainty for specific technical aspects, such as the connection of distributed energy resources to the grid or anti-islanding measures.[83] Some publications go further into the technical issues by calling for changes to grid codes and standards,[84] showing that for a complex topic such as microgrids, amending or adopting new laws and decrees may not suffice. There is this extra layer of very technical rules that also needs to be adapted, especially to deal with network issues (for connection and balancing, mainly).[85] However, some articles adopt a broader view and raise the issue of the applicability of the existing electricity regime to microgrid actors, such as when Heldeweg and Lammers argue for a legal regime for 'collective action […] to enable the factual operation of (smart) microgrids'.[86]

If microgrids are to be legally defined primarily for the EU legal set-up, the first decision to be made is regarding how to name them. There is the obvious option of using the term 'microgrid', but that is not the only one. Indeed, as section 3 shows,

79 2019 Electricity Market Directive (n 48) art 35

80 Soshinskaya and others (n 6) 661

81 Attanasio (n 22) 666

82 Wouters (n 6) 30

83 See, for example, Chris Marnay and others, 'Policy Making for Microgrids: Economic And Regulatory Issues of Microgrid Implementation' (2008) IEEE Power & Energy Magazine 69, 74–75; Soshinskaya and others (n 6) 666

84 See, for example, Kish and Lehn (n 22); Julia Merino, Patricio Mendoza-Araya and Carlos Veganzones, 'State of the Art and Future Trends in Grid Codes Applicable to Isolated Electrical Systems' (2014) 7 Energies 7936; Glenn Platt, Adam Berry and David Cornforth, 'What Role for Microgrids?' in Fereidoon P Sioshansi (ed) *Smart Grid – Integrating Renewable, Distributed & Efficient Energy* (Academic Press 2012) 185, 202

85 Merino, Mendoza-Araya and Veganzones (n 84) 7941

86 Heldeweg and Lammers (n 22) 483

the key distinguishing aspect of a microgrid is its temporary islanding capacity, not its size (which can vary and is never clearly established). A second option, therefore, would be to refer to such a system as a 'temporarily islanding network'. This would be clearer and more in line with reality, although it would also be at odds with the term used in the international literature.

Once this decision has been made, the concept needs to be defined. It should arguably be based on the main elements of the technical definition. Therefore, the results from the literature review as presented in section 2 would imply that any such legal definition ensures that microgrids integrate three key components (in ascending order of importance):

- They are local and rather small-scale networks. As seen in section 4, this can be better translated for a legal purpose with a cap on installed capacity or on the number of connected customers;
- They use flexibility technologies (storage, demand response, etc.) in order to remain balanced in all situations;
- They have the capacity to be temporarily islanded (ie they can disconnect, operate in islanded mode, then reconnect and resynchronise with the public grid).

It is not strictly necessary to specify that microgrids use RESs because most technical definitions do not differentiate between energy sources, and for a small-scale system, RESs are increasingly proving to be the most adapted and cost-effective solution anyway. It is, however, possible, although not compulsory either, to state in the definition that microgrids serve a specific purpose (eg to provide environmental benefits to its participants), as was done in EU law for the CECs.[87] To indicate in EU law that microgrids' final purpose is to contribute to the decarbonisation of the energy system would be in line with how they are already conceptualised in this jurisdiction, as mentioned in the introduction.

Interested lawmakers could be directed to an existing legal definition for microgrids already adopted in a (non-EU) country: the definition adopted in California in 2018. It reads:

> 'Microgrid' means an interconnected system of loads and energy resources, including, but not limited to, distributed energy resources, energy storage, demand response tools, or other management, forecasting, and analytical tools, appropriately sized to meet customer needs, within a clearly defined electrical boundary that can act as a single, controllable entity, and can connect to, disconnect from, or run in parallel with, larger portions of the electrical grid, or can be managed and isolated to withstand larger disturbances and maintain electrical supply to connected critical infrastructure.[88]

This case provides an example of a fairly extensive definition, with a range of possible actions for the microgrid actors. It illustrates the fact that a working legal definition

87 2019 Electricity Market Directive (n 48) art 2 (11) (b)

88 California Legislative Service, Public Utilities Code, (2018) Division 4.1, ch 4.5 s 8370 a (d), <https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=PUC&division=4.1.&title=&part=&chapter=4.5.&article> accessed 16 February 2022

must also be built around key terms that can themselves be defined, such as the terms 'demand response' or 'energy storage' for EU law.[89] However, adopting a legal definition will not automatically enable the development of microgrids. They need a regime, with adapted provisions for their actors and their rights and duties.

A legal regime for microgrids could apply the same rules as in the existing system – with the same rights and duties for network operators, electricity producers, etc. – or it can be a tailored regime with exemptions, for instance regarding unbundling rules. This legal regime can define whether microgrids are to be operated via a centralised or decentralised management system, or whether both options are open. It would be advisable not to restrain it to a limited set-up but to have the legal regime setting options, so that a microgrid can legally be run by a VIU or as a free market option (as detailed in section 5), according to the microgrid project promoters' choice. The main element that always needs to be clarified is the system operator's role. If VIU solutions are to be accessible, it must be possible for an integrated entity to manage energy production, distribution and supply, and thus to be exempt from unbundling rules if they exist. But the legal regime must also allow microgrid members to decide that the production and supply of energy shall not be in the hands of a VIU – a condition for the free-market and prosumer consortium models. In these cases, a clear regime is needed for separated grid operation, with cost bearing and a clear role for producers and suppliers, such as concerning their duties towards vulnerable customers. A clear regime for flexibility markets will be required as well if the microgrid is to reach profitability by selling grid services to the network operators. In most cases, there is no need to create a brand-new regime as one may already exist at a national or regional level, but it will usually have to be amended to some extent, given that 'the introduction and operation of microgrids takes place in an already heavily regulated domain [that] comes with many systemically locked-in legal obstacles'.[90]

To conclude, through the method and the reasoning applied, this article provided an example of how energy law research can integrate the findings from other disciplines (technical or not) in order to help lawmakers steering the energy transition.

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89 2019 Electricity Market Directive (n 48) art 2 (20) and 2 (59)
90 Heldeweg and Lammers (n 23) 487