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Design of local energy communities according to typologies. Example application of the metropolitan region of Barcelona

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Abstract

The development of local energy communities established in the EU legislation increases citizen participation and promotes collective ownership of renewable energies, thereby contributing to a more just and inclusive energy transition. However, there are still some information gaps due to factors such as an imprecise legal framework or a lack of reference examples. Especially in the context of larger cities, such as Barcelona, there have been few reference cases or scientific analyses of local energy communities so far.

The objective of the thesis is to analyse the current framework conditions and give technical as well as organizational recommendations on the design of local energy communities in the Metropolitan Area of Barcelona, both on a general level and with respect to two case studies of currently developing energy communities.

Based on a literature review, a framework of important context factors to be considered in the design of local energy communities as well as of possible configurations according to relevant technical and organizational characteristics is established. This information is complemented by a survey among existing energy communities in Spain and interviews with experts in the field.

The application of this framework to the Metropolitan Area of Barcelona shows that although certain barriers still exist, there is generally a great potential for the development of local energy communities due to aspects such as favourable conditions for solar energy or the presence of neighbourhood associations and other pre-existing community structures. Based on the analysis of the context, different technical and organisational recommendations are made. The design of a PV installation on an example roof could also illustrate that synergies can be created by including different consumer profiles in an energy community, such as office buildings, schools and households.

The thesis at hand is able to contribute to further research on contextual factors as well as on typologies of local energy communities. Moreover, the lack of case study analysis of local energy communities in the urban setting is addressed by applying the elaborated framework on the case of the Metropolitan Area of Barcelona.

Keywords:

Local energy communities, citizen energy, energy transition, renewable energy

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Abbreviations

AEB	Barcelona Energy Agency (*l'Agència d'Energia de Barcelona*)
AMB	Metropolitan Area of Barcelona (*Àrea Metropoliana de Barcelona*)
CCPP	Combined cycle power plants
CEC	Citizen Energy Community
EV	Electric Vehicle
GHG	Greenhouse gas
IDAE	Institute for the Diversification and Saving of Energy (*Instituto para la Diversivicación y Ahorro de la Energía*)
IEA	International Energy Agency
IEMD	Internal Electricity Market Directive (EU)
INECP	Integrated National Energy and Climate Plan
IP	Interview partner
JRC	Joint Research Centre (EU)
kWh	Kilowatt hours
MITECO	Ministry for the Ecological Transition and the Demographic challenge (*Ministerio para la Transición Ecológica y el Reto Demográfico*)
OR	Ordinary regime (electricity generation)
PNTE	National Pact for the Energy Transition of Catalonia (*Pacte Nacional per a la Transició Energètica de Catalunya*)
PMEC	Framework Program for Energy and Climate Action 2020-2023 (*Programa marc d'actuacions en energia i clima*) of the AMB
PRTR	Recovery, Transformation and Resilience Plan (*Plan de Recuperación, Transformación y Resiliencia*)
PV	Photovoltaic
REC	Renewable Energy Community
RED II	Renewable Energy Directive (EU)
REScoop	European federation of renewable energy cooperatives
RQ	Research question
SCCL	Sociedad Cooperativa Catalana Limitada
SP	Special regime (electricity generation)
W	Watt

1 Introduction

"Energy democracy and decentralization will only happen if power is transferred to individuals, households and communities."
(Otamendi-Irizar et al., 2022)

1.1 The energy crisis and the current energy system

Globally, energy is responsible for the largest share of greenhouse gas (GHG) emissions due to human activities (European Environment Agency, 2021). To mitigate climate change, a transformation of our energy system is indispensable. A central question is: How can we meet our increasing energy needs and at the same time comply with sustainability goals? This question does not only concern the areas of climate change or energy security, but also issues such as social inequality (García-Gusano and Iribarren, 2018).

Electricity prices for household consumers in Spain were already among the highest in Europe during the first half of 2021 (Eurostat, 2021). The current energy crisis in Europe has further exacerbated this situation: Compared to Q4 2018, the wholesale electricity price in Spain in Q4 2021 was three times higher (Pinheiro de Mato and Murillo Gili, 2022). This is particularly severe for people already at risk of energy poverty, which can be defined as "the manifestation of social inequality in energy consumption and inadequate access to energy services, due to a combination of low incomes, high energy prices and inefficient homes" (Walsh, Castanié and Giovannini, 2020). In Barcelona, where energy poverty is acknowledged a major urban problem, the project "*Indicadors municipals de pobresa energètica a la ciutat de Barcelona*" ("Municipal indicators of energy poverty in the city of Barcelona") was implemented. It was estimated that in 2016, about 170.000 people were affected. Moreover, it was found that electricity is the supply for which there are most cases of debt for non-payment, cut-off notices and cuts (Tirado Herrero, 2018).

Currently, the Spanish energy market is dominated by large companies. The energy oligopoly consists of only five companies that are in control of 95% of Spain's electricity generation, 99.7% of the distribution and 79.5% of commercialisation (Pellicer-Sifres et al., 2018). Due to centralisation processes, the citizens have gradually lost their power and new models are required reversing this process (Otamendi-Irizar et al., 2022). Pellicer-Sifres et al. (2018) describe the situation of the market as follows: "The Spanish electricity market is characterised by considering electricity as a commodity, and consequently, the supply is cut off when energy bills are not paid, without considering specific social situations and family composition." The complex regulations are often criticized for making it difficult for consumers to understand the energy market as well as hindering the expansion of renewable energy and self-consumption. Citizen energy, such as local energy communities, is a concept that can address this problem by keeping benefits within the local economy, creating jobs, lowering electricity bills and reducing dependence on the energy oligopoly (Amigos de la Tierra, 2021). It addresses not only the climate crisis, but also ecological and social issues and is therefore an essential element to be considered on Spain's energy transition path.

The majority of the energy supply and demand in Spain is currently met with fossil fuels (**figure 1-1**). According to the 2021 Energy Policy Review of the International Energy Agency (IEA, 2021), 72% of the total energy supply as well as 68% of the total final consumption are based on fossil fuels. Spain, like all EU member states, is required to publish a National Energy and Climate Plan 2021-2030 (NECP; Plan Nacional Integrado de Energía y Clima, PNIEC), in line with the Paris Agreement reached in 2015. The objectives of Spain's NECP until 2030 include a reduction of GHG emissions by 23% with respect to 1990 (MITECO, 2021a; IEA, 2021).

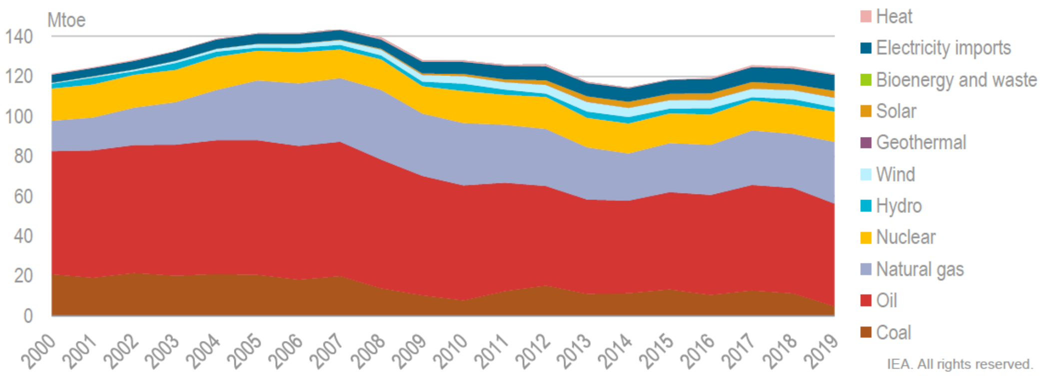

Figure 1-1: Spain's total energy supply by source, 2000-2019 (IEA, 2021)

The current framework for energy and climate of Spain not only foresees a reduction of emissions and an increase in the share of renewables, but also a transformation of the energy system: Self-consumption of renewables as well as distributed generation shall be expanded. According to the IEA (2021), this implies a shift from a power sector "characterised by centralised generation based on base load and peak demand needs with mostly passive demand to a new model marked by variable, decentralised, intelligent and interconnected generation".

To overcome the current technical observed maximum share of renewable energy in Spain, the following measures must be taken according to Hoicka et al. (2021): 1) redesigning the energy system logic and architecture, 2) increase the social acceptance of system changes among different types of stakeholders. It is commonly perceived that the collective ownership of renewables, such as in local energy communities, increases their acceptance and can substantially contribute to an energy transition. In fact, with measure “1.13 Local energy communities” (“*Comunidades energéticas locales*”) of Spain’s NECP, the promotion of local energy communities is proposed and new players in the energy transition are introduced.

The energy transition is also being driven forward on a regional and local level: Catalonia aspires to achieve an energy model based on 100% renewable energy by 2050. The base document for establishing the National Agreement for the Energy Transition of Catalonia (“*Pacte Nacional per a la Transició Energètica de Catalunya*”) was approved in 2017. In October 2021, a new energy transition roadmap was presented, which focuses on a distributed energy model and aims at encouraging citizen participation and self-consumption (Institut Català d'Energia, 2022). Also at the local level of Barcelona, there is a commitment to becoming 100% renewable by 2050. The Climate Plan (‘Pla CLIMA’), compatible with the Paris Agreement, was published in 2018. Moreover, at the beginning of 2020, the municipality published a Climate Emergency Declaration, which proposes major changes to the energy model. To counteract the climate emergency, the current consumption model based on fossil fuels shall be reversed and self-consumption as well as local generation of renewables are considered key. The City Council of Barcelona (“*Ajuntament de Barcelona*”) formulates the following as one of the most important challenges (Ajuntament de Barcelona, 2021a): “**Making shared self-consumption a reality by developing physical and virtual energy communities**”. Also, the Framework Program for Energy and Climate Action 2020-2023 (PMEC; “*Programa marc d’actuacions en energia i clima*”) of the metropolitan authority Metropolitan Area of Barcelona (AMB; “*Àrea Metropoliana de Barcelona*“) specifically considers energy communities (AMB, 2020).

It becomes evident that at the national, regional and local levels, citizen participation is seen as a contributor to a just and inclusive energy transition. A new actor has entered the path to an energy model based on renewables: local energy communities.

1.2 Local energy communities to support the energy transition

1.2.1 Definitions around local energy communities

It is difficult to retrieve a single definition of the term "local energy communities" because there are many related and overlapping concepts (e.g. “community energy” or “citizen energy”) or terms (e.g. “renewable energy community”, “citizen energy community”, “sustainable energy community”, “clean energy community” or “low carbon community”), some of them broader or narrower (Gjorgievski, Cundeva and Georghiou, 2021). Also, diverse forms of energy communities exist across Europe. This lack of clarity about what exactly defines a local energy community is on the one hand seen as a risk factor, especially where the concept is incorrectly implemented or misused, e.g. for greenwashing. On the other hand, too narrow a definition could inhibit innovation and result in too little adaptation to local contexts (Hicks and Ison, 2018).

In the process of developing European legislation, two definitions of energy communities have evolved: Within the Clean Energy Package of the EU, which will be discussed in more detail in chapter 1.3, energy communities were included in two different laws and as two different figures: While the Renewable Energy Directive (EU) 2018/2001 introduces the so-called renewable energy communities (REC), the Internal Electricity Market Directive (EU) 2019/944 takes up citizen energy communities (CEC). Although there is no legal form explicitly for "(local) energy communities" (neither in EU nor in Spanish law), these two figures come closest. They are defined as illustrated in **table 1-1**.

Table 1-1: Definition of renewable energy communities and citizen energy communities in EU legislation

Renewable Energy Directive (EU) 2018/2001	Renewable Energy Community (REC)	**Article 2(16):** Legal entity (a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; (b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities; (c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits
Internal Electricity Market Directive (EU) 2019/944	Citizen Energy Community (CEC)	**Article 2(11):** Legal entity that (a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises; (b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and (c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders

Both definitions part from the establishment of a legal entity (oftentimes, this is a cooperative, although no specific legal form is given in EU legislation) as a collective action and are based on the following common elements (Caramizaru and Uihlein, 2020):

- **Governance:** Participation must be open and voluntary
- **Ownership and control:** Effective control by members or shareholders, which can be natural persons, certain enterprises or local authorities
- **Purpose:** The primary purpose should be value-driven instead of focusing on commercial purposes and financial profits

However, both concepts also have differences. For example, the geographical scope of RECs is limited to the proximity of the project, while there is no limitation for CECs. Moreover, RECs can carry out projects on different types of energy (apart from electricity also e.g. heat) as long as it is renewable energy, while CECs can operate only in the electricity sector, including projects with renewable energy (MITECO, 2021a). Moreover, in CECs, only small enterprises can be members, while RECs also include SMEs.

In line with the EU definition, the Spanish electricity sector law (*ley 24/2013, de 26 de diciembre, del Sector Eléctrico*), defines RECs as legal entities based on open and voluntary participation, controlled by members that are located in close proximity to the renewable energy project and whose primary purpose is to provide environmental, economic or social benefits rather than financial gain. According to IDAE (2022a), the main aspects that differentiate energy communities from traditional actors in the sector are: revenues are primarily used to provide environmental or socio-economic services to members of the local community; project stakeholders have strategic and managerial control; internal decision-making is based on democratic governance, ensuring that the autonomy of the community is maintained.

In addition to the definitions given in the respective legal texts, various organizations have also provided definitions of the term. The Barcelona Energy Agency (AEB, "*l'Agència d'Energia de Barcelona*") defines local energy communities as "a community of natural persons, SMEs or local administrations located near a renewable-energy project", who "benefit from the energy generated by this installation". Requirements include an "open, voluntary participation of its members, and its main objectives must be environmental, economic or social benefits for its partners and members or the area around the project" (Energia Barcelona, 2021). Definitions can be also found in scientific journal articles, such as the one given by Bukovszki et al. (2020), who define energy communities as "as a collective of actors voluntarily mobilized around a shared objective relating to energy - either shared management of energy systems or collective purchasing of energy".

It is important to note that local energy communities go beyond mere collective self-consumption. While collective self-consumption is focused on a specific activity and not explicitly on an organizational format, energy communities refer to the formation of legal entities complying with specific governance principles that can implement a variety of energy-related projects far beyond self-consumption (Frieden et al., 2019). **Figure 1-2** shows a conceptual design of a local energy community, with households as basic units, which can invest in local generation technologies such as solar photovoltaics (PV) and in energy management or storage systems.

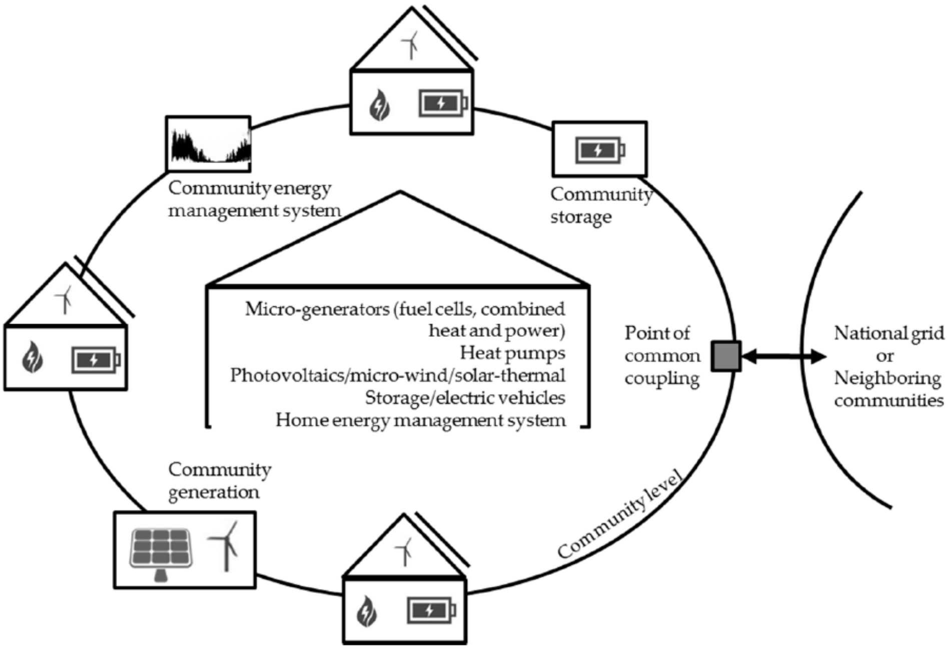

Figure 1-2: Conceptual design of an energy community (Koirala et al., 2016)

Local energy communities may be engaged in many different activities, such as energy generation, consumption, distribution as well as supply. They can be classified in diverse ways, for example with respect to the technology applied. According to a study performed by the EU Joint Research Centre (JRC), solar energy and wind are the most commonly used energy technologies (Caramizaru and Uihlein, 2020). The literature review (chapter 2) will explore the different possible configurations and characteristics of local energy communities in more detail.

1.2.2 Benefits of local energy communities

Local energy communities are an important instrument for putting the citizen at the centre of the energy transition and turning consumers into so-called “prosumers”, giving them a proactive role (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018; Caramizaru and Uihlein, 2020; IDAE, 2022a; Otamendi-Irizar et al., 2022).

Some important benefits of local energy communities within the context of an inclusive and democratic energy transition are listed below (Berka and Creamer, 2016; Brummer, 2018; Caramizaru and Uihlein, 2020; Manso-Burgos et al., 2021).

- **Acceptance of RE:** The possibility of participation as well as the retention of generated benefits within the local community **increases the local support for renewable energy** and helps mitigate the "Not in my back yard" (NIMBY) effect.
- **RE generation targets:** Energy communities facilitate the **integration of renewable energies** into the system through demand-side management.
- The fact that **energy is produced closer to the point of consumption** in leads to lower energy losses, increases flexibility as well as consumer resilience.
- **Climate protection and sustainability:** The promotion of renewable energies and energy efficiency measures contribute to a generation of heat and/or electricity without relying on fossil and polluting fuels. This has environmental benefits through the **reduction of GHG emission**.
- Many energy communities also carry out projects targeted at energy efficiency, leading to lower electricity consumption. In addition, more use is made of renewables. Both aspects lead to a **reduction in energy dependency and the cost of energy supply** for the community.
- Self-consumption projects can provide affordable heat or electricity from renewable sources resulting in **economic savings** for families and can thus help **tackling energy poverty**. This is especially the case where the cost of alternative fuels is relatively high. Many energy communities have implemented solidary schemes, where financially vulnerable families pay a reduced or no quota.
- **Community empowerment and self-realization:** The possibility for everyone to form part of an energy community **increases social cohesion**, community feeling and trust.
- Energy communities also represent an opportunity for people living in apartment buildings or with limited financial means, for example, to invest in renewables and get engaged in local self-consumption. This implies a **more inclusive energy transition** based on the empowerment of citizens within the energy system giving them greater responsibility for the self-provision of their energy needs.
- The **development of local jobs and businesses** directly or indirectly related to the renewable energy sector is promoted.
- In case of projects with active user engagement, participants can improve their **energy literacy and consumption behaviour**. Citizens are empowered towards joint action against climate change.

In the long run, the success of local energy communities will also depend on the extent to which they can deliver benefits in a cost-effective way for the members and the energy system in general (Caramizaru and Uihlein, 2020).

1.3 Regulatory framework for local energy communities and current status

1.3.1 European legislation

In the Clean Energy package, the EU recognized the right of citizens and communities to directly participate as actors in the energy sector, thereby bringing forward the vision of a prosumer-centred energy union (Caramizaru and Uihlein, 2020). It represents an update of the EU's energy policy framework in order to comply with the commitments for emission reductions made in the Paris Agreement of 2015. At the cornerstone of the package are the already mentioned Renewable Energy Directive (EU) 2018/2001, RED II, and the Internal Electricity Market Directive (EU) 2019/244, IEMD. Therefore, since 2018, community energy has been legally anchored in the EU. Both directives set out the framework for energy communities as new market actors combining non-commercial purposes with environmental and social objectives (Caramizaru and Uihlein, 2020). They define two types of energy communities, namely RECs (RED II) as well as CECs (IEMD), and provide principles of understanding and operating them (Tounquet et al., 2019).

Article 22 (1) of the RED II establishes:
"*Member States shall ensure that final customers, in particular household customers, are entitled to participate in a renewable energy community while maintaining their rights or obligations as final customers, and without being subject to unjustified or discriminatory conditions or procedures that would prevent their participation in a renewable energy community, provided that for private undertakings, their participation does not constitute their primary commercial or professional activity*."

Overview on important EU legislation for energy communities

- **Directive (EU) 2018/1999** on the Governance of the Energy Union and Climate Action
- **Directive (EU) 2018/2001** on the promotion of the use of energy from renewable sources ("Renewable Energy Directive", RED II)
- **Directive (EU) 2019/944** on common rules for the internal market for electricity ("Internal Electricity Market Directive", IEMD)

According to the RED II, member states shall "provide an enabling framework to promote and facilitate the development of renewable energy communities" (Article 22, (2)). The adoption of the EU legislation in national law can increase the certainty for investors as well as their potential for replicability. The European Federation of Renewable Energy Cooperatives, REScoop, maintains a transposition tracker to assess the status of the adoption of the figures of RECs and CECs in EU member states according to aspects such as the reflection of the criteria of EU definitions, cooperative principles, allowance of specific legal entities, citizen participation or appointment of a designated authority for monitoring (REScoop, 2020a).

The transposition map, providing an overall qualitative assessment based on a modified traffic light grading system, as of May 2022, is displayed in **figure 1-3**. It becomes evident that the implementation of the European directives on energy communities into national law is deficient in many countries so far. Various organisations such as NGOs have already criticised the insufficient implementation. In Germany, for example, which is currently assigned to the category "Bad Transposition" in the REScoop transposition tracker, associations such as the German Alliance for Citizen Energy ("*Bündnis Bürgerenergie*") have lodged a complaint with the European Commission and are calling for infringement proceedings against Germany. Amongst other aspects, it is criticized that there is still no legislation specifically targeting energy communities (Bündnis Bürgerenergie, 2021).

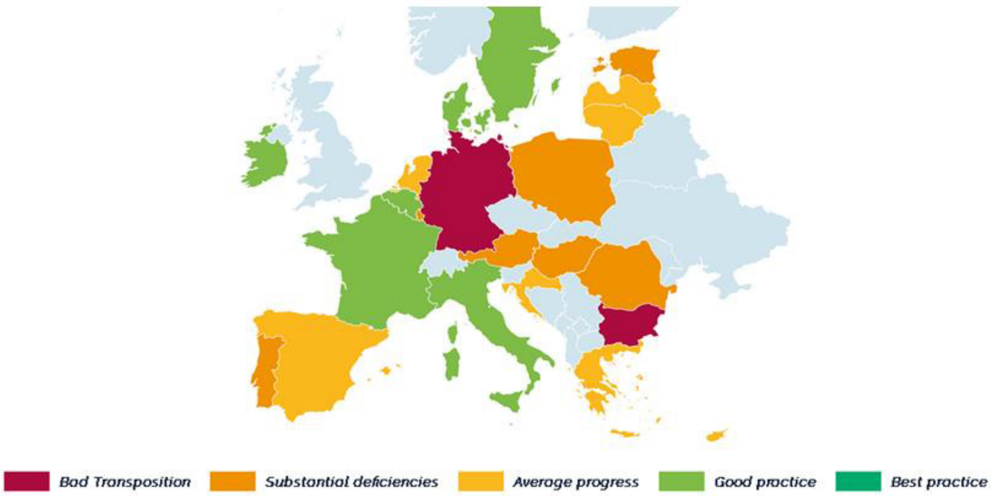

Figure 1-3: Status of the transposition of the RED II into national law as of May 2022 (REScoop, 2020a)

In Spain, too, the implementation of the European directives is criticised from different sides, such as the NGO Amigos de la Tierra, and a re-sharpening is demanded as will be described in the next section.

1.3.2 Spanish national framework and regional framework of Catalonia

As mentioned before, Spain's NECP includes measure 1.13 that focuses on actions to develop the legislation to define and promote the entities of RECs in line with the EU definition. The responsible bodies for the measure are the Ministry for the Ecological Transition and the Demographic challenge (*Ministerio para la Transición Ecológica y el Reto Demográfico*, MITECO) and the Spanish Institute for the Diversification and Saving of Energy (*Instituto para la Diversivicación y Ahorro de la Energía*, IDAE). In 2019, the IDAE published a guide on the promotion of energy communities, giving an introduction on local energy communities and covering topics such as challenges and success factors, international and national experiences, the support framework in Spain or types of energy communities (IDAE, 2019).

The Royal Decree 244/2019 of October 5 represents an important step for the development of energy communities as it repealed the so-called sun-tax and improved the conditions for self-consumption in Spain. Amongst others, it enables groups of apartment owners or industrial estates to engage in collective self-consumption (Frieden et al., 2019). The regulation stipulates that, in order to benefit from collective self-consumption, the participants associated to the generation point(s) shall sign a sharing agreement determining a distribution coefficient for each participant.

The legislative framework for self-consumption so far allowed only for static allocation coefficients, meaning that they are the same each hour of the year, not taking into account the variation in consumption of each consumer. It is often stated that the full potential of local energy communities can only be unlocked if variable coefficients based on the actual demand curves are promoted (Manso-Burgos et al., 2021). With the new Order TED/1247/2021, accepted on November 5, the government has approved variable energy sharing for shared self-consumption. The distribution may vary for each hour of the year and may be modified every four months. This ex-ante definition quite in advance means that the coefficients might still divert substantially from the actual consumption. However, it is a progress in the legislation compared to fixed coefficients. Self-consumption can be isolated or with a connection to the grid (**figure 1-4**).

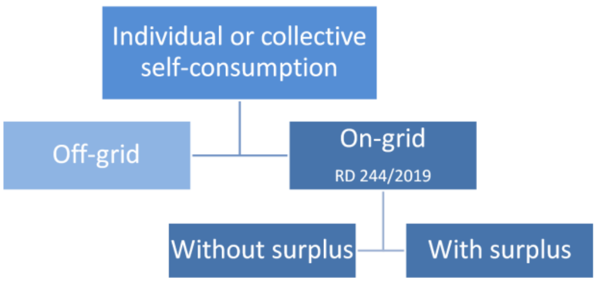

Figure 1-4: Modalities of self-consumption (based on RD 244/2019)

The Royal Decree 244/2019 covers the following modalities of self-consumption with connection to the grid (Frieden et al., 2019):

- **Self-consumption without surpluses** (through the installation of an antifouling mechanism, the injection of surplus energy into the distribution network is prevented)
- **Self-consumption with surpluses** (excess energy produced may be injected into the distribution networks)

In case of self-consumption with surpluses, two cases are possible: Self-consumption without compensation or with (simplified) compensation. Self-consumption without compensation implies selling the excess energy to the marketer ("*comercializadora*"), at the updated price of the electricity market. However, this requires different formalities, such as the registration as a producer. The modality with compensation means that in case not all of the energy is consumed, the surplus can be injected into the distribution network so that at the end of each billing period, the marketer compensates for the surplus energy.

Moreover, the Royal Decree on self-consumption establishes several conditions specific for **collective** self-consumption:

- The associated consumers must be connected to the **same transformer substation** and the power distribution must be **low voltage**.
- There must be a **maximum distance of 500 m** between the PV plant and each of the associated consumers.
- The production of the solar panel project and the self-consumers must be registered under the same **cadastral reference** (taking into account the first fourteen digits).

The concept of local energy communities was introduced in the Spanish legislation in 2020 with the Royal Decree 23/2020 of June 23. In the same year, Royal Decree 960/2020 of November 3 was adopted, which promotes the diversity of actors in the deployment of renewables, among other aspects. Also, in the following year, Law 7/2021 was published, which aims at facilitating the decarbonisation of the Spanish economy based on the NECP in order to comply with the objectives of the Paris Agreement. For example, the law takes up the involvement of the public in the energy transition.

Overview on important Spanish national legislation for energy communities
• **Real Decreto-ley 15/2018**, de 5 de octubre, de medidas urgentes para la transición energética y la protección de los consumidores [*urgent measures for the energy transition and consumer protection*] • **Real Decreto 244/2019**, de 5 de abril, por el que se regulan las condiciones administrativas, técnicas y económicas del autoconsumo de energía eléctrica [*administrative, technical and economic conditions for the self-consumption of electricity*]

- **Real Decreto 23/2020**, de 23 de junio, por el que se aprueban medidas en materia de energía para la reactivación económica [*approving energy measures for economic recovery*]
- **Real Decreto 960/2020**, de 3 de noviembre, por el que se regula el régimen económico de energías renovables para instalaciones de producción de energía eléctrica [*economic regime of renewable energies for electricity production facilities*]
- **Ley 7/2021**, de 20 de mayo, de cambio climático y transición energética [*climate change and energy transition*]
- **Orden TED/1247/2021**, de 15 de noviembre, por la que se modifica, para la implementación de coeficientes de reparto variables en autoconsumo colectivo, el anexo I del Real Decreto 244/2019 [*implementation of variable distribution coefficients in collective self-consumption*]
- **TED/1446/2021**, de 22 de diciembre, por la que se aprueban las bases reguladoras para la concesión de ayudas del programa de incentivos a proyectos piloto singulares de comunidades energéticas (Programa CE Implementa), en el marco del Plan de Recuperación, Transformación y Resiliencia [*approving the regulatory bases for the granting of aid under the programme of incentives for unique pilot projects for energy communities (EC Implementa Programme), within the framework of the Recovery, Transformation and Resilience Plan*]

In September 2021, the government of Spain announced the activation of 100.000.000 euros in aid to boost energy communities within the framework of the Recovery, Transformation and Resilience Plan (*"Plan de Recuperación, Transformación y Resiliencia"*, PRTR) and published in December TED/1446/2021 as the regulatory basis. The plan, financed by the EU program NextGenerationEU is divided into three centrally managed programmes: CE-Aprende (i.e. learn), CE-Planifica (i.e. plan) and CE-Implementa (i.e. implement). Moreover, a network of Community Transformation Offices will be established across the country to advise energy communities throughout their development and facilitate access to the mentioned programmes (MITECO, 2021b). The selection of projects is based on different criteria, for example whether the members are exclusively natural persons, SMEs or local entities and located in the vicinity of the project, or whether it is a multi-component and innovative project (IDEA, 2022b).

It is estimated that by 2030, local energy communities could produce 148'610 GWh in Spain, more than only with self-consumption (Amigos de la Tierra, 2021b). At the moment, the concept of local energy communities is still at an early stage of development and implementation in Spain, but more and more projects are appearing with progresses in the legislation. In the transposition tracker of REScoop, the transposition of the EU directives in Spain is currently assessed as "average progess". This is more advanced than some other countries, but still there are different deficiencies mentioned, for example there is no concrete delimitation of the types of legal entities that RECs could adopt or there is no designated authority (REScoop, 2020a). Also in Spain, different experts and organisations have criticised the implementation so far. For example, it is demanded that the radius of action of energy communities, which is currently limited to 500 m, be extended. Moreover, it is demanded that a project that is participatory should be granted advantages in order to be able to compete with more powerful and dominant players in the electricity sector, e.g. an advantage should result from the fact that the electricity in an energy community is not transported many kilometres over the grid (Herrera, Fresco and Navarro, 2022).

In Catalonia, policy regarding energy and energy transition is based on the National Pact for Energy Transition ("*Pacto Nacional para la Transición Energética de Cataluña*", PNTE), approved on January 31, 2017, the adoption of Law 16/2017, of August 1, on climate change, the Climate and Environmental Emergency Declaration ("*Declaración de emergencia climática y ambiental*") on 14 May 2019 as well as Decree Law 16/2019, of 26 November, on urgent measures regarding the climate emergency and the promotion of renewable energies (Diputación de Barcelona, 2021). Moreover, Decree Law 24/2021 was adopted in 2021, which amends Law 16/2017 including the provision of renewable, distributed and shared generation targets until 2030. One of the aims of Law Decree 24/2021 is to simplify administrative processes in the field of self-consumption of electricity and facilitate agreements among neighbours of a community to install renewable energy systems. Catalonia has 32'570'000 euros at its disposal from the Next Generation funds destined to promoting self-consumption installations (Generalitat de Catalunya, 2021).

Overview on important Catalan legislation for energy communities

- **Ley 16/2017**, de 1 de agosto, del cambio climático [*climate change*]
- **Decreto ley 16/2019**, de 26 de noviembre, de medidas urgentes para la emergencia climática y el impulso a las energías renovables [*urgent measures for the climate emergency and the promotion of renewable energies*]
- **Decret llei 24/2021**, de 26 d'octubre, d'acceleració del desplegament de les energies renovables distribuïdes i participades [*acceleration of the deployment of distributed and shared renewable energies*]

In order to disseminate and promote public ownership and management of networks of electricity distribution, a total of 74 municipalities and four entities in Catalonia have constituted on 23 February 2022 the Association of Municipalities and Entities for Public Energy (*"Asociación de Municipios y Entidades para la Energía Pública"*, AMEP). The aim is to reach an energy transition, where the social right to energy access is guaranteed and where citizens and companies can generate their own renewable energy and share their services.

1.4 Problem definition

In the previous chapters it became clear that local energy communities are an important instrument for a just and participatory energy transition. However, factors such as the differing baseline situations in different countries, an imprecise legal framework as well as the lack of reference examples in many places mean that there are often still information gaps and a common concept of local energy communities still needs to be found. The compilation and analysis of existing cases can make an important contribution.

In the Metropolitan Area of Barcelona, there are only a few cases so far, but due to the growing importance of the energy community figure, both among various citizens' associations and in politics, it can be assumed that more projects will emerge in the coming years. This raises the need for an analysis of the existing framework conditions and the factors that should be taken into account when designing an energy community in Barcelona.

1.5 Objectives and scope

The overall objective is to assess the current situation and give organizational and technical recommendations on the design of local energy communities in the Metropolitan Area of Barcelona, both on a general level and with respect to two case studies.

With this objective in mind, three research questions are formulated as well as sub-questions. The state-of-the-art research on local energy communities, including context factors and characteristics relevant for their design, shall be identified. Moreover, an objective is to create an overview of the characteristics of existing communities and to collect challenges to be considered, success factors and best practices, through the analysis of existing energy communities in Spain as well as expert interviews.

This framework of important context factors to be considered in the design as well as possible configurations of energy communities (typologies) will then be applied to the context of the Metropolitan Area of Barcelona, reviewing current cases and developing technical and organizational recommendations for the design of a local energy community. Although the more detailed analysis is focused on two case studies of local energy communities currently emerging in Barcelona, also general recommendations shall be derived.

Table 1-2 provides an overview of the research questions as well as the respective research approach.

Table 1-2: Research questions

Research questions (RQ)	Research approach
RQ 1: What can be learned from literature and research to date on local energy communities? 1.1 What is the **state-of-the-art research** on local energy communities? 1.2 Which **context factors and characteristics** are important to be considered in the design of local energy communities (which types of local energy communities exist)?	Literature review → **Chapter 2**
RQ 2: What can be learned from practical examples of local energy communities already established? 2.1 Which **types and characteristics** of local energy communities can be identified? 2.2 What are **barriers** to be considered as well as **best practices and success factors** related to the design of local energy communities? 2.3 What is the **current situation** regarding the implementation of local energy communities in Spain and specifically in the Metropolitan Area of Barcelona?	Background study: Survey among existing energy communities & Expert interviews → **Chapter 3**
RQ 3: Based on the learnings from RQ 1 and RQ 2, which recommendations (organizational and technical) can be made regarding the design of local energy communities in the Metropolitan Area of Barcelona? 3.1 How are the **framework conditions (context)** for the creation of a local energy community in Barcelona? 3.2 Which **design** is recommended for the creation of local energy communities in the Metropolitan Area of Barcelona?	Case study & Mapping with GIS & Technical design with K2Base and PVGIS → **Chapter 4**

The geographical scope of the thesis is Spain for the background study and the Metropolitan Area of Barcelona for the case study. Further, the recommendations are focused on technical and organizational aspects, excluding financial aspects. At the technical level, the focus is on electricity and, as energy technology, on solar PV, as this is identified as the currently most widespread technology for local energy communities. Thus, for example, solar thermal energy is not specifically addressed.

1.6 Methodology

The methodology includes different layers to collect the required information, which serves as a basis to develop recommendations for the creation of local energy communities in Barcelona. The first step is a review of the state-of-the-art research and further publications with relation to local energy communities. In a second step, a background study is conducted including a survey among existing energy communities in Spain as well as interviews with experts in the field. The insights gained are then applied to the case of Barcelona.

1.6.1 Literature review and the state-of-the-art research on energy communities

To answer **RQ 1** ("What can be learned from literature and research to date on local energy communities?"), a literature search for peer-reviewed academic journal articles related to local energy communities was performed. The main databases browsed for keywords such as "local energy communities", "renewable energy communities", "design of local energy communities" or "citizen energy" were *Google Scholar*, *ResearchGate* and the *UPC Bibliotècnica* (the digital library of the Universitat Politècnica de Catalunya).

After a first screening of the aspects discussed in the reviewed publications, the following thematic fields were identified to be of high relevance and the information was organized accordingly:

- Overview of the most important articles and reports identified **(→ Chapter 2.1)**
- Barriers and challenges **(→ Chapter 2.2)**
- Enabling factors (technical and non-technical) **(→ Chapter 2.3)**
- Process of designing local energy communities **(→ Chapter 2.4)**
- Contextual factors to be considered **(→ Chapter 2.5)**
- Properties and characteristics to be considered in the design of energy communities (possible configurations) **(→ Chapter 2.6)**

The contextual factors (chapter 2.5) were grouped according to the four critical categories of contextual factors for community renewable energy defined by Hicks and Ison (2018): Physical factors, technology factors, institutional factors as well as community factors.

In case of the properties and possible characteristics of energy communities (chapter 2.6), it was found that most of the characteristics can be classified as organizational or technical aspects. In addition, financial aspects are highly relevant in the development of an energy community. However, the scope of the thesis is on technical and organizational aspects, as already mentioned in chapter 1.5.

1.6.2 Background study

1.6.2.1 Questionnaire

To gain a better understanding of possible configurations of local energy communities, what difficulties exist, and what approaches to success exist, a survey was conducted of local energy communities in Spain that already exist or are in the process of being formed.

In the first step, cases of local energy communities in Spain were identified via internet search as well as in existing best-practice collections or interactive maps (Aliente, 2021; REScoop, 2020b; "*Germinador Social"* award). Due to the still imprecise definition in the legislation, projects that self-identify as energy communities as well as projects that are listed in collections or interactive maps on local energy communities were generally considered. The background to the decision not to set strict criteria for the selection of practice cases was also to identify boundary cases and critical characteristics, especially in view of a very broad definition in the legislation.

The initial information retrieved online (e.g. on website of the projects) was organized in a Microsoft Excel spreadsheet detailing some main characteristics as identified in the literature search: organizational form, activities, energy technology, technical characteristics (procedure with surplus energy, installed potential).

In order to verify and complete the information retrieved as well as to clarify qualitative questions, a survey was conducted among the identified energy communities. The questionnaire was created in Microsoft Word and structured according to RQ 2.1 ("Which types and characteristics of local energy communities can be identified?") and RQ 2.2 ("What are barriers to be considered as well as best practices and success factors related to the design of local energy communities?"):

- Part I: Characteristics of the energy community → **RQ 2.1**
- Part II: Learnings (challenges and success factors) → **RQ 2.2**

The questionnaire (s. **Annex A**) includes both open-ended and closed-ended questions. Based on the completed questionnaires, the characterisation of the energy communities in the Excel sheet was adapted and further completed. Moreover, lessons learned were extracted regarding challenges and success factors. The data was then evaluated both quantitatively (e.g. installed potential) and qualitatively (e.g. lessons learned).

1.6.2.2 Expert interviews

In order to shed light on **RQ 2.3** ("What is the current situation regarding the implementation of local energy communities in Spain and specifically in the Metropolitan Area of Barcelona?") as well as to enrich the information retrieved in the literature review and the survey among existing cases, interviews with experts in the field of local energy communities were conducted. The focus of the expert interviews was therefore the contextual and institutional aspect, but also the identification of energy communities in order to potentially add further cases to the survey. However, interviews were also conducted with local energy communities that offered to conduct a phone interview instead of completing the questionnaire as well as with interview partners for the case studies in Barcelona.

The selection of interview partners, which are anonymized in this thesis, was based on the identification of relevant organisations in the analysis of literature and publications, as well as on recommendations from interview partners and contacted organisations. **Figure 1-5** provides an overview of the types of organizations interviewed as well as the respective thematic areas covered. A more detailed overview of the interviews conducted is available in **Annex B**.

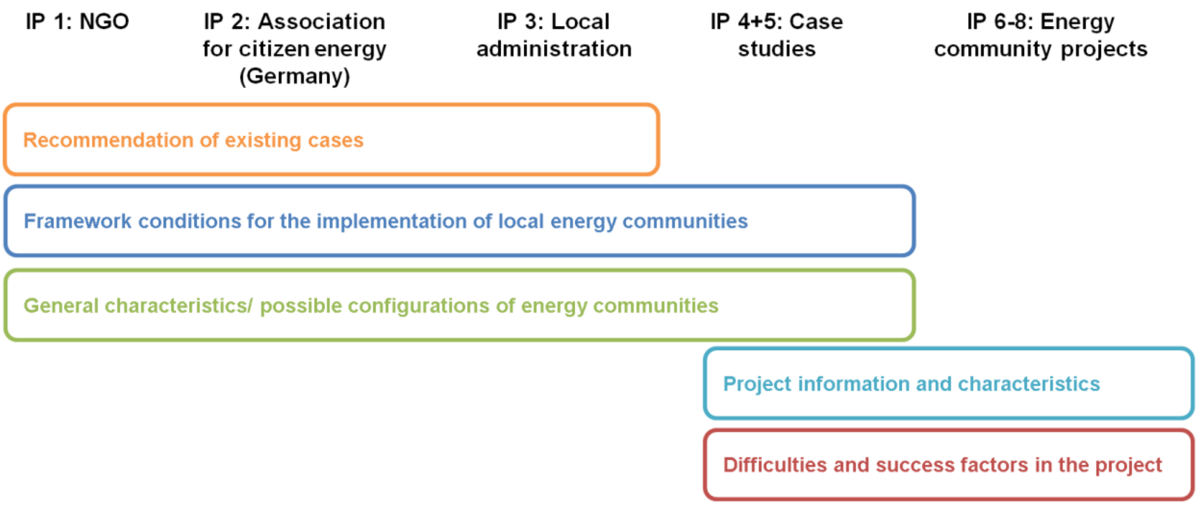

Figure 1-5: Interview partners (IP) and thematic fields of interviews (own elaboration)

The interviews were conducted via online video call or phone call, and the duration ranged from 30 to 45 minutes. Based on a general common structure, the questions were then partly tailored towards each interview partner and semi-structured. This is in line with Mattes, Huber and Koehrsen (2014), who evaluated semi-structured, qualitative interviews as being "the most appropriate data collection method for capturing the complex and multi-layer character of local change processes".

1.6.3 Case study

The findings from the previous steps are then used to respond to **RQ 3** ("Based on the learnings from RQ 1 and RQ 2, which recommendations (organizational and technical) can be made regarding the design of local energy communities in the Metropolitan Area of Barcelona?"). First, the background of two reviewed case studies of local energy communities currently developing in Barcelona is described. Based on the structure of the literature review in chapter 2, contextual factors are first analysed (**RQ 3.1**: "How are the framework conditions (context) for the creation of a local energy community in Barcelona?") and then recommendations are made on important characteristics and configurations (**RQ 3.2**: "Which design is recommended for the creation of local energy communities in the Metropolitan Area of Barcelona?").

Figure 1-6: Procedure for the analysis of the case of local energy communities in Barcelona (own elaboration)

Figure 1-6 shows the approach chosen for the analysis of the case of the Metropolitan Area of Barcelona. For the **contextual analysis**, the aspects identified in the literature review were complemented by a document analysis specific to the Barcelona case, for example regarding the current energy mix or the available energy resources.

The recommendations on the **organizational design** are based on the literature review and the results from the background study. The recommendations on the **technical design** include the following steps:

<u>Step 1:</u> Creation of an overview of suitable roofs in the Metropolitan Area of Barcelona

The visualization and identification of suitable roofs was realized in **QGIS** and **GoogleEarth™**. The following data were used in QGIS:

- Base map: Orthophoto of Catalonia (Institut Cartogràfic i Geològic de Catalunya, 2022)
- Shapefiles: Municipal and district boundaries of the city of Barcelona (Open Data BCN, 2015), metropolitan facilities (Área Metropolitana de Barcelona, 2022a)
- Spatial data (point data): map with PV generation on municipal buildings (Ajuntament de Barcelona, 2021c)

The latter dataset was extracted from an interactive online map of energy generation on municipal buildings provided by the City Council (Ajuntament de Barcelona, 2021c). The location of the existing rooftop PV installations was exported in Excel and, by identifying the corresponding coordinates, the data was included as point data in QGIS. The result is a map of municipal buildings in the Metropolitan Area of Barcelona, detailing the roofs which already have a PV installation in place as well as those without an installation. Recommendations are then made on the identification of suitable roofs.

Step 2: Description of physical energy assets and example design

An design for an example roof was created with **K2 Base** (K2 Systems GmbH, 2022), a free online tool for solar PV design, which was developed by the company K2 Systems, a producer and developer of mounting systems for PV installations.

The design in K2 Base involves the following aspects:

1. **General project details** (location, name etc.)
2. **Environmental load** (wind load, snow load)
3. **Roof:** Draw the design area (select roof type, shape etc.) and mark the roof surface; then define all the remaining characteristics of the roof (e.g. building height, material); optionally, obstacles can be marked
4. **Design the module arrays** (at the end, the number of modules and the peak capacity of the array is shown):
    a. define module (manufacturer and model)
    b. define mounting system
    c. optionally define thermal gaps (e.g. thermal gap every 8 modules)
5. Create the **summary**: Number of modules, peak potential [kWp]
6. **Export:** e.g. in Excel

With **PVGIS**, a web application developed by the European Commission (Joint Research Centre, 2020), the yearly PV energy production [kWh] of the example PV system was calculated. The calculation takes into account the type of PV module, the solar radiation, wind speed and temperature. The yearly PV production was compared with average energy consumption patterns.

Step 3: Recommendations on information and communication technologies (ICT)

Step 4: Recommendations regarding the connection to the grid

The recommendations for steps 3 and 4 are based on the literature review and the background study, taking into account relevant aspects identified in the contextual analysis.

All in all, the analysis covers important elements of the determination of the PV potential according to the scheme of Mavsar et al. (2019), represented in **figure 1-7**.

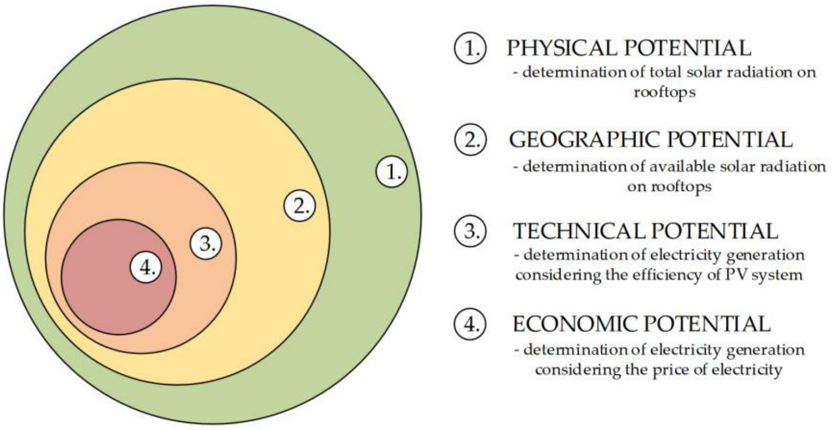

Figure 1-7: Hierarchical methodology for the determination of PV potential (Mavsar et al., 2019)

- **Physical** potential = Climate and solar radiation (data obtained from **PVGIS**)
- **Geographic** potential = Identification of suitable rooftops with **QGIS** and **Google Earth™** (rooftop geometry, superstructures on the roof, inclination and slopes, shading effects)
- **Technical** potential = Calculation of the estimated electricity production with an example installation (online tool **K2Base**)

As financial aspects are not included in the recommendations, the economic potential was not taken into consideration.

1.7 Thesis structure

Following the introduction to the thematic area in **chapter 1**, the thesis is structured according to the steps described in the methodology and displayed in **figure 1-8**.

Figure 1-8: Structure of the Master's Thesis, RQ = research question (own elaboration)

In **chapter 2**, the literature review referring to RQ 1 is presented, with sub-chapters structured according to identified topics discussed in the reviewed publications. The background study (RQ 2), including the results from the review of existing local energy communities as well as the expert interviews is presented in **chapter 3**.

As an output of chapters 2 and 3, information will have been gathered regarding context factors and characteristics relevant for the design of local energy communities, the setting of existing communities, the current situation and preconditions for the creation of local energy communities, as well as challenges and success factors. Drawing upon this information gathered, **chapter 4** presents an analysis of the specific context of the Metropolitan Area of Barcelona and recommendations on the design of local energy communities (with specific consideration of two cases), thereby addressing RQ 3.

2 Literature review

"A reason for the diversity of projects embraced by the LEC concept is that community energy projects have emerged for decades in many countries with no specific regulation."
(Manso-Burgos et al., 2021)

2.1 Overview on relevant publications identified

The following chapters present the results of the review of relevant publications. Important challenges, enabling factors, procedural steps as well as relevant contextual factors and characteristics that should be considered in the design of local energy communities are described, thereby answering RQ 1.

Using the search process described in chapter 1.6.1, various publications were identified. Based on a first review of the topics covered in the different publications, the information was then clustered into aspects relevant for the design of energy communities: Barriers and challenges, enabling factors, design process, context factors, and characteristics of energy communities.

Table 2-1 provides an overview of the identified publications and the topic areas covered in each case.

Table 2-1: Overview of the publications identified for the literature review on energy communities

Publication	Barriers and challenges	Enabling factors	Design process	Context factors	Characteristics of ECs
Braeuer et al. (2021)	X				X
Brummer (2018)	X				
Bukovszki et al. (2020)		X	X	X	
Capellán-Pérez, Campos-Celador and Terés-Zubiaga (2018)	X	X			X
Caramizaru and Uihlein (2020)				X	X
Comodi et al. (2019)					X
Frieden et al. (2019)					X
Gjorgievski, Cundeva and Georghiou (2021)	X	X	X	X	X
Gómez Navarro et al. (2021)				X	
Hicks and Ison (2018)				X	

Hoicka et al. (2021)					X
Lazdins, Mutule and Žalostība (2021)	X			X	X
Lowitzsch, Hoicka and van Tulder (2020)	X	X		X	X
Mattes, Huber and Koehrsen (2014)				X	
Mutani, Santantonio and Beltramino (2021)				X	
Otamendi-Irizar et al. (2022)		X		X	X
Palm (2021)	X	X	X	X	
Romero-Rubio and Andrés Díaz (2015)				X	X
Tounquet et al. (2019)					X
Walsh, Castanié and Giovannini (2020)	X				X

While compiling the information and writing the texts, the collection of publications was supplemented by targeted searches on specific topics not covered (sufficiently) in the previously identified publications on energy communities. This concerns aspects related to the context factors or certain characteristics of energy communities. **Table 2-2** presents these complementary publications.

Table 2-2: Publications identified in a complementary search on specific topics

Publication	Barriers and challenges	Enabling factors	Design process	Context factors	Characteristics of ECs
Adam et al. (2016)					X
Bartolini et al. (2020)					X
Cox et al. (2018)				X	
Fakhraian et al. (2021)				X	
Kazmi et al. (2021)					X
Lee, Flores-Espino and Hurlbut (2017)				X	
Mignacca, Locatelli and Velenturf (2020)				X	
Summeren et al. (2020)					X
Tapiador (2009)				X	

2.2 Barriers and challenges

Different barriers were identified in the publications retrieved that can hinder the development and growth of energy communities. These concern both the general context (the external circumstances) in which the project is located, as well as possible internal challenges that may arise. Thematically, the identified challenges were classified into the following clusters: technical system, socio-economic and cultural conditions, organizational and governance issues, institutional and market setting as well as aspects related to the interplay of actors.

2.2.1 Technical system

According to Gjorgievski, Cundeva and Georghiou (2021), technical barriers mostly result from the limitations of the distribution network capacity, the intermittency of renewable energy generation and the mismatch between the local demand and supply. The connection to the grid can represent a significant challenge (Brummer, 2018; Gjorgievski, Cundeva and Georghiou, 2021; Palm, 2021). Particularly in areas with low population density, energy communities might face the problem of high grid connection costs. A possibly negative attitude of grid operators towards small renewable energy projects and a low incentive for them to connect small operators can complicate the situation (Brummer, 2018; Walsh, Castanié and Giovannini, 2020). There are examples of citizen energy projects where ownership of the local grid was assumed, such as the case of EWS Schönau, a community-owned energy cooperative in Germany. However, so far these are only individual examples whose feasibility depends strongly on the local context.

A lack of technical expertise can also represent a barrier for energy communities. This expertise is required for the clarification of various questions, for example, regarding the choice of energy technology (e.g. whether PV is the most suitable solution for local energy production), regarding if and how demand response affects the effectiveness of the community, or with respect to the modelling of different technical solutions. Here, of course, external help is often involved, for example from engineering firms (Lazdins, Mutule and Žalostība, 2021).

Another possible challenge is represented by the spatial requirements for different energy generation technologies, the associated land use or environmental aspects, e.g. with relation to water (Gjorgievski, Cundeva and Georghiou, 2021). In the case of rooftop PV installations in urban areas, for example, energy communities are faced with the challenge of identifying roofs that are suitable in terms of various characteristics, such as geometry or shading, and at the same time have a suitable ownership model. This is further complicated by the generally lower energy density of renewables compared to nuclear or fossil energy and the associated pressure on the use of space, especially in urban areas (Lowitzsch, Hoicka and van Tulder, 2020).

Lastly, the availability of domestic central energy sources at a cheap price can hinder the development of local energy communities (Palm, 2021). However, under the current energy crisis with increasing prices, as described in chapter 1.1, a tendency towards decentralized renewable energy systems can be observed.

2.2.2 Socio-economic and cultural conditions

The development of citizen energy projects depends heavily on the local community. For example, a lack of awareness of the benefits of using renewable energy systems or low trust in the community model can make it difficult to establish and build an energy community, to attract members or to gain acceptance among the local population (Walsh, Castanié and Giovannini, 2020; Lazdins, Mutule and Žalostība, 2021). This not only concerns the general public as potential members: Also a lack of knowledge and understanding, for example of the cooperative model, among politicians, bankers or potential partners can represent a barrier (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018).

In general, limited experience among the core group in setting up a local energy community can be a difficulty that needs to be resolved. Further possible informational and knowledge gaps include the impact of different variables on energy production, a lack of reliable energy generation and demand data or a lack of modelling solutions (Lazdins, Mutule and Žalostība, 2021). As the history of local energy communities in Spain is still quite young and many projects are just in the process of implementation, these informational and awareness barriers certainly occur more frequently. This illustrates the importance of an exchange between different actors and groups as well as sharing best practices.

Further socio-economic aspects that can represent barriers include high investment costs of lack of access to finance and high membership fees in relation to low disposable income (Braeuer et al., 2021 ;Palm, 2021).

2.2.3 Organizational and governance issues

In addition, energy community projects often face different challenges related to organisational and governance aspects of the group. One aspect is the size of the community. In Spain, many renewable energy cooperatives have experienced a quasi-exponential growth with respect to the number of members as well as in relation to electricity retailing. Although this can be seen as a sign of success, membership growth and territorial spread can also make it more difficult for individual members to actively participate in comparison to a reduced group with regular face-to-face relationships. This also requires a higher degree of professionalization and appropriate tools to manage participation (Palm, 2021). On the other hand, the very small size of some communities might create the problem that they are not able to generate enough surpluses to cover relatively high organizational costs (Brummer, 2018).

Generally, the social and structural arrangements created for the group, also with respect to the legal form, influence its stability. It is also important to consider that many energy communities have a high degree of dependence on voluntary work or outside support (Brummer, 2018; Gjorgievski, Cundeva and Georghiou, 2021). With respect to social arrangements, a possible hurdle is represented by internal group conflicts or weak communication between the different actors (Walsh, Castanié and Giovannini, 2020; Lazdins, Mutule and Žalostība, 2021).

Braeuer et al. (2021), who focus on energy communities in multi-family buildings, point out that in these settings, the principal-agent dilemma needs to be overcome, implying that "internal revenue streams need to provide value for both the principal and the agent, i.e. the landlord and the tenant respectively".

The engagement of possible participants and partners is also a challenge met by energy community projects. To attract and retain members or partners, it is important to appropriately communicate the idea as well as the technical background to an audience that might not have detailed technical knowledge. Networking and communication activities are also resource-intensive (Brummer, 2018).

2.2.4 Institutional and market setting

An institutional setting with a lack of support for energy communities and their absence on the political agenda can be a general obstacle to the emergence and development of projects. A poorly defined legislative framework or a discrimination against small actors in the energy system can hinder the creation of energy communities (Gjorgievski, Cundeva and Georghiou, 2021). The financing of energy communities is also often one of the biggest challenges, especially if there is a lack of access to renewable energy support schemes. Tailor-made policies are needed for energy communities, which give them advantages and make them competitive with respect to existing industry and infrastructure (Lazdins, Mutule and Žalostība, 2021).

Lazdins, Mutule and Žalostība (2021) mention several market failures that represent barriers for energy communities, such as an underinvestment in market R&D activities, low GHG emission quota prices, the monopoly of energy generation and utility companies as well as an unaffordability of solutions based on renewable energy sources.

With respect to the legislative framework, an often discussed issue is the definition of local energy communities in legal texts. While a too narrow definition might exclude some appropriate projects or discourage some new initiatives, a very broad definition might also include for example projects involving multi-national companies which might not represent a true empowerment of the consumer (Palm, 2021).

Administrative burdens and bureaucratic issues are also frequently mentioned challenges. This includes aspects such as the planning permission or bureaucratic barriers to grid connections and micro grid operations. These time-consuming procedures are often rather designed for big companies and can pose major challenges for energy communities, especially in their initial phase (Walsh, Castanié and Giovannini, 2020).

2.3 Enabling factors

The identified enabling factors were grouped into technical and non-technical aspects, analogous to the approach of Gjorgievski, Cundeva and Georghiou (2021).

2.3.1 Technical

Gjorgievski, Cundeva and Georghiou (2021) distinguish between two types of technical prerequisites enabling the operation of an energy community: the basic technologies in the physical layer and those related to the virtual layer. It has to be noted, however, that not all local energy communities need an advanced technical infrastructure. This is the case, for example, for communities consisting solely of consumers.

In the physical layer, the following elements can be considered enabling factors (Gjorgievski, Cundeva and Georghiou, 2021; Palm, 2021):

- **Technologies and suitable conditions to generate energy locally**, such as solar PV, wind or biomass. The possibility and efficiency of the use of these technologies in turn depends on environmental conditions, which therefore also function as enabling factors. The specific conditions that favour efficient energy production are of course highly dependent on the respective technology. In case of wind energy, for example, optimal conditions with respect to wind speed or air density benefit the project, while for solar PV appropriate solar radiation can be seen as enabling aspect (s. chapter 2.5). Even if the physical environmental factors are beneficial, suitable surfaces must be found, e.g. roofs in the case of rooftop PV. The availability of such land or surfaces and, depending on ownership, the willingness of the parties involved (e.g. the municipality) to cooperate, is another enabling aspect.

- **Demand-side flexibility**, which is offered by technologies such as batteries, thermal storage or EVs (s. chapter 2.6).
- **Access to a reliable power grid** and an **advanced metering infrastructure** (consisting of smart meters, a communication system and a network) allow actors to share energy within the community more efficiently.
- **Quality assurance** of the technological infrastructure in order to meet standards related to reliability, quality and security of energy sources.
- **Lower installation costs** of renewable energy installations compared to conventional energy also represents an enabling factor.

At the virtual level, the following examples can be seen as beneficial for the operation of an energy community (Otamendi-Irizar et al., 2022; Bukovszki et al., 2020; Gjorgievski, Cundeva and Georghiou, 2021):

- Integration of an **energy management system** that allows controlling the elements of the physical layer.
- **Digitization** as a tool for monitoring and evaluating data on production, consumption, savings etc.

2.3.2 Non-technical

2.3.2.1 Engagement and governance

Important for both the acceptance of the project and the engagement of participants is a base community of interested and active consumers motivated to support the project over time. Of course, it cannot be expected that every citizen will participate and contribute to the same extent. An important prerequisite is therefore a group of active local initiators who drive the project forward (Gjorgievski, Cundeva and Georghiou, 2021). A multidisciplinary core group should be formed that acts as a facilitator and collaborates with local administrations (Otamendi-Irizar et al., 2022).

A governance model based on collaboration and citizen power is important for the success of energy communities. Another aspect of governance to be considered is the management of benefits. While in some cases, the benefits are represented by the savings due to the provision and consumption of renewable energy, there are also projects where reinvestment opportunities arise (Otamendi-Irizar et al., 2022).

Depending on the goals and context, an energy community can pursue an expansion strategy over time (corresponding to social scaling, in this case actor-base expansion, according to **figure 2-1**). An advantage of a higher number of members is, for example, that the financial capacity increases, which could be an enabler to operate in the retailing market or build additional energy infrastructure. Also, it might make it possible to hire staff, which is important in an expansion, as most energy communities depend largely on volunteer work (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018). When expanding, an appropriate balance among economies of scale and social cohesion should always be maintained (Bukovszki et al., 2020).

2.3.2.2 Inward and outward cooperation

The term "community" in itself already stands for the cooperation and collaboration of different actors. Close cooperation within the core group, but also with other members, is highly relevant for the success. Equally important is an outward collaboration to reach as many members of the general public as possible and to establish an effective network with relevant actors and organisations, such as local administrations (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018). Collaborations with other actors can be formalized through different ways, for example by creating a consortium or through stipulations in contracts. The contact with advisory service centres and umbrella organisations can also be very valuable to energy communities, especially in the early stages, as they can function as intermediaries with politicians or as platforms for learning and networking (Palm, 2021). In Spain, this role could be assumed, for example by the Community Transformation Offices established under the Transformation and Resilience Plan described in Chapter 1.3.

Otamendi-Irizar et al. (2022) describe it as problematic when participatory work is not carried out in projects or the consensus of the neighbours is not obtained. It is recommended to follow proven methodologies such as living labs to work closely with the local community. Cooperation with other energy communities is also an enabling factor. The exchange of experiences, best-practice approaches and the creation of possible synergies benefits all parties involved (Bukovszki et al., 2020).

2.3.2.1 Enabling institutional and market context

Policies and regulations aimed specifically at energy communities, incentive programmes as well as a clear definition increase the likelihood of energy community projects being established and their chances of success. State funding and subsidy mechanisms as well as debt securities are also enabler for energy communities. A CO_2 tax can also ensure that large energy companies have to pay for the externalities of fossil energy.

Liberalized energy markets make it possible for new players to participate in the energy business alongside traditional energy companies (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018). A high dependency on foreign fossil fuel resources is also mentioned by Palm (2021) as a driver of the emergence of more renewable energy communities.

2.4 Process of setting up a local energy community

Bukovszki et al. (2020) examined various case studies and created, based on them, a generalised project lifecycle of an energy community, which is divided into five phases: initiation, design and implementation, operation and further development (either social or technological scaling).

The design phase in the project lifecycle according to Bukovszki et al. (2020) was further specified with the three pillars of creating an energy community described by the organization *Red de Comunidades Energéticas S.Coop* (2022): the technical project, the governance plan and the financing plan. The result is displayed in **figure 2-1**.

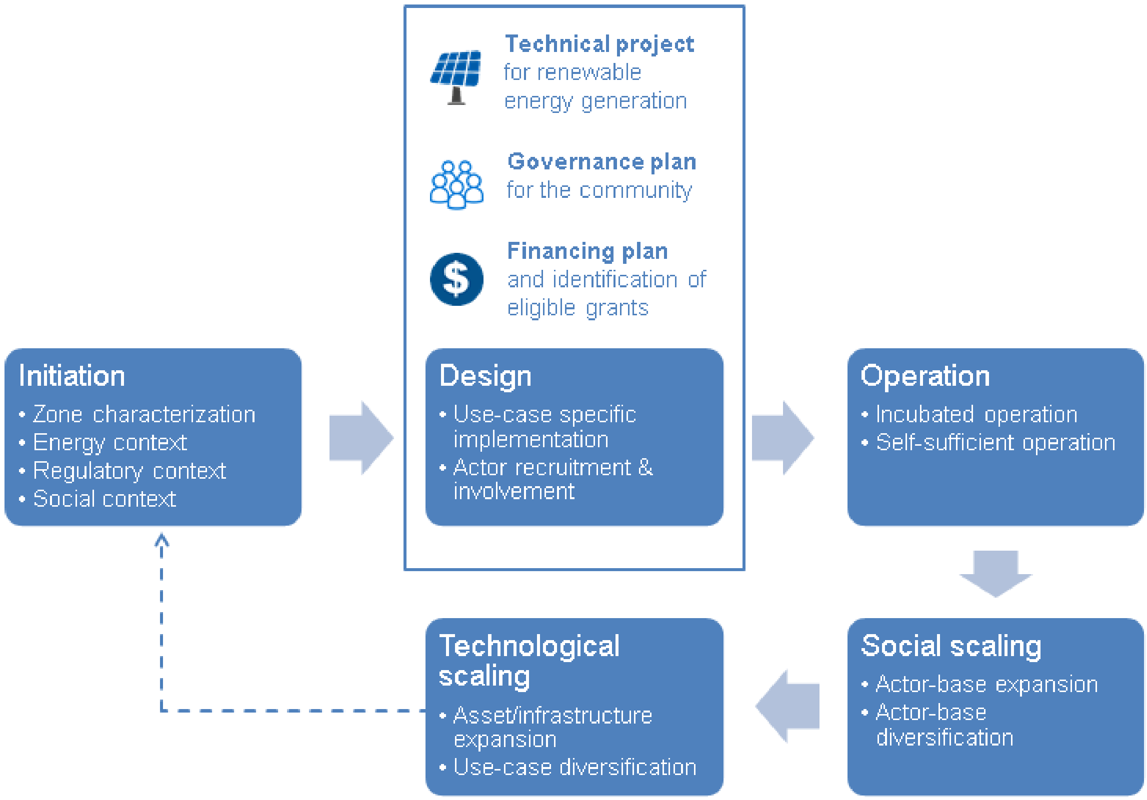

Figure 2-1: Project lifecycle of a local energy community (adapted from: Bukovszki et al., 2020; Red de Comunidades Energéticas S.Coop, 2022)

It is important to note that the complexity of the design phase depends strongly on the respective use case. Gjorgievski, Cundeva and Georghiou (2021) describe the following modelling tasks included in the design phase for energy communities:

1. **Modelling of the goals and desired impacts** (including the goals of energy community members (environmental (climate protection), economic or social goals) as well as of other stakeholders, e.g. policy makers or energy suppliers).

2. **Modelling of the local energy systems** (e.g. PV arrangements using commercial software and taking into consideration the defined goals such as improving self-consumption or the use of storage units).

2.5 Context factors to be considered (Initiation Phase)

With the barriers and enabling factors relevant for energy communities described in Chapters 2.2 and 2.3 in mind, the following sections summarize different context factors that are recommended to be analysed when initiating a local energy community. In short, it can be said that contextual factors represent constraints (or enablers) that define the opportunities and the viability of an energy community project. The analysis of the contextual factors coincides with the “Initiation” phase according to **figure 2-1**, which involves an analysis of the characteristics of the area, the local energy sources, the regulatory context and of the community.

Accordingly, the chapter is structured according to the four critical categories of contextual factors for community renewable energy defined by Hicks and Ison (2018): Physical factors, technology factors, institutional factors as well as community factors.

2.5.1 Physical factors

A zone characterization delivers information on the physical potential, such as the availability of solar, wind or bioenergy resources, and defines the technology and scale opportunities of a project (Hicks and Ison, 2018; Bukovszki et al., 2020). It represents the maximum energy limit of the resource, e.g. the sun’s total energy received (Fakhraian et al., 2021). Research has shown that there is a relation between the number of energy communities in a country and the availability of natural resources (Palm et al., 2021).

Renewable energy resource data provide information on the intensity and availability of e.g. sun, wind or biomass at a specific geographic location. Also, **local climate conditions** such as temperature or precipitation are considered. For example, PV efficiency is related to air temperature, which can cause higher or lower energy output (Cox et al., 2018). Moreover, the **topography** forms part of the physical context factors. This includes geospatial data such as slope or elevation. Digital elevation models (DEM) provide important information on topographical features such as terrain slope or hill shading (Lee, Flores-Espino and Hurlbut, 2017; Cox et al., 2018).

The factors that are considered in the renewable energy resource assessment depend on the energy technology chosen.

Solar resources are typically assessed based on the quantity, intensity or temporal distribution of solar irradiation. The three key types of solar data are (Tapiador, 2009, Cox et al., 2018):

- *Direct normal radiation* (radiation that hits Earth directly and is not affected by clouds)
- *Diffuse radiation* (radiation that has been scattered, e.g. resulting from cloud absorption)
- *Global radiation* (the sum of direct and diffuse radiation, i.e. the total amount of solar radiation that hits a flat surface)

For PV technology, the global radiation should be considered, as both direct and diffuse radiation is relevant. It is important to analyse the uncertainty in radiation data, as it is directly correlated with uncertainties in lifecycle savings for PV systems (Tapiador, 2009).

Although the majority of energy communities currently use PV technology, there are also cases of other technologies, for example wind or biomass. In case of **wind energy**, for example, the most relevant characteristics for a resource assessment are wind speed, wind direction or continuity (Tapiador, 2009). The potential for **biomass energy** is determined by the biomass resource available (i.e. the density of different types of biomass feedstocks and the amount of energy contained) within a specific geographical area (Cox et al., 2018).

Related to the physical potential, the **geographic urban potential** should also be considered, for example in case of local energy communities in urban areas using PV. It refers to the conditions represented by the built environment, such as the rooftop PV potential and includes characteristics such as: rooftop geometry (inclinations, slopes, superstructures located on the rooftop etc.), other buildings or shading effects from trees (Fakhraian et al., 2021).

The relevance of a more specific analysis of physical factors as part of the initiation phase varies from area to area. When establishing an energy community with energy production based on solar energy in Catalonia, for example, it can generally be assumed that there are favourable conditions with respect to solar irradiation. In general, Spain enjoys an abundance of renewable energy resources (Romero-Rubio and Andrés Díaz, 2015). However, knowledge of the characteristics mentioned is in any case relevant for calculating potential energy production.

Summary of physical context factors:

- Renewable energy resources
- Local climatic conditions
- Topography
- Geographic (urban) potential

2.5.2 Technology factors

The technology context factors determine the viability of a specific technology within a particular community and the electricity generation potential. These aspects include: energy needs and demand profile of the community or building; current electricity generation mix; the cost of different renewable energy technologies; maturity and modularity of the technology; existing infrastructure (Hicks and Ison, 2018).

Energy needs and the demand profile of a community or a building are key components of the energy context. As mentioned in chapter 2.3.1, demand-side flexibility can be considered a technical enabling factor. For this reason, it is important to be aware of, for example, the variation in the load, both over the day and over the year. Chapter 1.3.2 has already dealt with the modifiable distribution factors in the context of Order TED/1247/2021. Since the distribution factors here can be adjusted every four months, it is therefore important to have knowledge about the change in consumption.

With respect to the energy needs, it is also relevant whether it is an urban context, as the spatial density of energy demand in urban centres can be significantly higher than the spatial density of renewable energy production. This also highlights the importance of tailored solutions. In urban areas, frequent tailored solutions include (Lowitzsch, Hoicka and van Tulder, 2020): solar PV, district energy as well as energy efficiency, demand response or other flexibility options.

The **current energy mix** in a place also plays a role in the emergence of energy communities. High energy dependence is considered an enabler for energy communities, while the availability of cheap domestic energy sources represents a barrier. The same applies to energy contexts, where a lot of people already own a PV installation and therefore might not consider it a benefit to participate in an energy community (Palm et al., 2021).

In general, **cost** is an important determinant of which technology a community will pursue (Hicks and Ison, 2018). The relative costs compared to non-renewables are also particularly relevant for the viability of local energy communities, including the installation costs. Also, energy prices in general determine the possibilities for energy community projects: For example, increased energy prices in Spain in 2012 have led to an increase in energy cooperatives (Caramizaru and Uihlein, 2020).

A higher **maturity** of an energy technology, i.e. its development stage, will probably result in more favourable conditions, such as with respect to costs, applicability or efficiency. **Modularity** is also mentioned as a relevant technology factor. For example, high modularity is often cited as a major advantage of PV energy as it is therefore applicable in a greater range of physical contexts (Hicks and Ison, 2018). It also has to be noted that modularity is considered an important aspect with relation to circular economy, as it decouples the lifetime of the modules from other infrastructure. Therefore, the modularity of a technology should also be considered in the context of sustainability goals of an energy community (Mignacca, Locatelli and Velenturf, 2020).

Another important technology factor is the **existing energy infrastructure**, such as the transmission infrastructure (Cox et al., 2018). Access to a reliable power grid is an important enabling factor and the general conditions for small renewable energy projects to connect to the grid as well as the grid operator’s attitude have to be considered.

Moreover, depending on the set-up, an energy community might be impacted by the status of the **roll-out of smart-meters**, electronic instruments that facilitate the management of the grid and allow selling locally produced electricity to end-users in the proximity (Gjorgievski, Cundeva and Georghiou, 2021; Palm, et al, 2021).

In case of energy communities, where the PV system is installed externally instead of on-site, virtual metering is regarded an innovative solution. These virtual power plants can be defined as “interconnected small, decentralised and usually privately-run RES power producers and storage facilities” that jointly sell their energy and gain access to the market more easily than it would be the case individually. This means that people who do not have direct access to an installation that produces energy can still participate and share electricity, thereby becoming prosumers (Palm et al., 2021).

The viability of a technology at a certain location is also influenced by **land or monument protection** (Lee, Flores-Espino and Hurlbut, 2017). For example, the installation of rooftop PV on listed buildings is more complicated due to preservation aspects.

Summary of technology context factors:

- Energy needs and the demand profile
- Energy mix
- Cost of technologies
- Maturity and modularity of technologies
- Existing energy infrastructure
- Roll-out of smart-meters or other ICT
- Land or monument protection

2.5.3 Institutional factors

Another important area that has an impact on energy communities is the institutional or regulatory context. During the initiation phase, aspects such as the regulatory requirements as well as synergies (or counter-synergies) with policy targets should be analysed (Bukovszki et al., 2020). According to Mutani, Santantonio and Beltramino (2021), "it is crucial for EC to rely on the political support of the local governments and institutions to integrate energy planning at territorial scale with the existing urban and territorial plans".

The status of energy communities on the political agenda is a decisive influencing factor for the success of a project (Romero-Rubio and Andres Dias, 2015). Renewable energy targets also have an impact, for example whether a certain percentage of final energy consumption is to come from renewables (Romero-Rubio and Andres Dias, 2015). Moreover, the inclusiveness of an energy transition process towards renewable energy, for example, with regard to citizens, defines the possibilities for bottom-up initiatives (Mattes, Huber and Koehrsen. 2014).

The availability of financial incentives for energy communities or renewable energy support schemes represents an important part of the context and to be considered in the initiation phase, particularly against the background of oftentimes high up-front investments. State funding and subsidy mechanisms or policy tools promoting renewables include tax incentives, grants and feed-in-tariffs (Palm, 2021).

The regulatory framework and the definition of energy communities in legal texts is also an important part of the context. It must be carefully examined at the beginning of an energy community project in order to choose the configurations, such as the legal figure or the modality of self-consumption, accordingly. For example, energy communities in Spain should be aware of the limit of 500 m between energy generation and consumption. In countries where local energy communities are not yet recognised as a figure, there is a risk that they are subject to the same regulatory standards as conventional energy (Bukovszki et al., 2020).

The commitment of the local administration is another context factor to be considered, as it often plays an important role in facilitating the implementation of local energy communities as well as their future development. Moreover, local authorities often form part of the core group initiating an energy community project (Otamendi-Irizar et al., 2022).

In connection with the local authorities, the administrative burden must also be taken into account, as initiators of a project often face high bureaucratic hurdles. The core group should analyse the administrative requirements and be prepared to deal with possible hurdles (Palm, 2021).

Lastly, the institutional framework conditions include the structure of the energy market. It has been explained before that the role of energy communities as small actors in the energy system can be challenging in the view of possible oligopoly situations of large players. Liberal energy markets that make it possible for new players to participate in the energy business, offer better conditions for local energy communities. Also, the investment in R&D activities and the dependency on foreign fossil fuel resources are market aspects that play a role (Lazdins, Mutule and Žalostība, 2021).

Summary of institutional context factors:

- Political agenda and policies promoting energy communities
- Availability of financial incentives
- Regulatory framework
- Commitment of the local administration
- Administrative and bureaucratic conditions
- Structure of the energy market

2.5.4 Community factors

The last of the contextual factors that should be analysed is the base community, i.e. the social context and the possible network formed with other actors.

First of all, an important basic requirement for an energy community project is that there is a base community of interested and active consumers that are motivated to form part of the project over time. In order to gain participants as well as acceptance among the community, the awareness of the benefits of using renewable energy systems and a certain sensitivity to environmental issues are important prerequisites. It has been also determined in chapters 2.2 and 2.3 that skills and knowledge in the community, for example regarding technical aspects, can hinder or enable energy community projects and should be therefore considered.

A tradition of local energy activism or a tradition of acting in groups and associations can contribute to the development of energy communities (Romero-Rubio and Andres Dias, 2015). Cultural and historic aspects have proven to be a relevant context factors, as they can shape for example the attitude towards a cooperative model. In many Eastern European countries, negative connotations are associated with cooperatives due or centrally-planned economies due to the historic context (Caramizaru and Uihlein, 2020).

When performing an analysis of the community context, different demographic indicators should be taken into account, which can be related to the motivation of members to join in and which should be taken into account in decisions regarding the size, type or design of a project (Romero-Rubio and Andres Dias, 2015; Caramizaru and Uihlein, 2020). This includes aspects such as population density, the level of disposable income (determining the financial ability to invest), e.g. GDP per capita, or the education level. A correlation was found between higher levels of education and the level of engagement in community energy projects (Caramizaru and Uihlein, 2020). Also, the classification of the context, e.g. rural or urban, frames the context of energy communities, for example regarding to the grid connection or the complexity of the network of involved actors.

In generally, the commitment and involvement of politicians, bankers or other actors as possible partners to form a network should be considered. Also, the availability of advisory service centres and umbrella organisations is a relevant part of the community context.

Lastly, the cooperation with other energy communities can be beneficial. Experimental model actions that generate so-called ‘core communities’ can contribute to the removal of barriers and expand progressively. Examples of core communities are educational centres, public facilities or social movements (Otamendi-Irizar et al., 2022).

Summary of community context factors:

- Awareness, attitude and skills of the base community
- Cultural and historic context
- Demographic indicators
- Classification (rural/urban)
- Commitment and involvement of politicians, bankers or other actors as possible network partners
- Availability of advisory service centres and umbrella organisations
- Existence of “core communities”

2.6 Characteristics relevant for the design of energy communities (Design Phase)

Local energy communities can be categorised in many different ways, for example according to the type of energy system implemented. This chapter explains different characteristics and possible configurations of local energy communities to be considered in the "design" phase, i.e. the use-case-specific implementation. As shown in **figure 2-1**, the design phase should include the technical project, the governance plan and the financing plan. Since this thesis focuses on technical and organisational aspects, the following subchapters are divided accordingly, with 2.6.1 focusing on technical aspects and 2.6.2 on organizational aspects.

The contextual factors described in chapter 2.5 influence the possibilities and decisions in the design phase. The challenges and enabling factors identified in chapters 2.2 and 2.3 will also be considered here. For example, since aspects such as cooperation with different actors or demand-side flexibility were seen as enabling factors, the aim here is to explain what options exist to implement this in an energy community.

2.6.1 Technical aspects

2.6.1.1 Energy technologies

In general, renewable energies are considered well suited for decentralised generation, either through off-the-grid networks ("islands") or by feeding electricity back into the grid and, for example, receiving a fixed feed-in tariff (Caramizaru and Uihlein, 2020). Still, aspects such as intermittence and variability have to be taken in to account (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018) as well as the generally reduced energy density [W/m^2] compared to conventional generation, meaning that less power can be produced with a given surface area (Lowitzsch, Hoicka and van Tulder, 2020).

Solar PV is one of the most frequently chosen technologies for energy communities due to various advantages, such as modularity or simplicity (Gjorgievski, Cundeva and Georghiou, 2021). There are many examples of solar cooperatives in Spain or the South of France, due to favourable climatic conditions. Rooftop PV installations make use of existing infrastructure and thus reduce the impact of land use due to the deployment of distributed generation (Adam et al., 2016). This is particularly relevant in areas with a high construction density, such as in cities.

A study of 24 community energy projects conducted by the Joint Research Centre (JRC) of the European Commission (Caramizaru and Uihlein, 2020) found that 38 % of the reviewed projects use solar energy (**figure 2-2**).

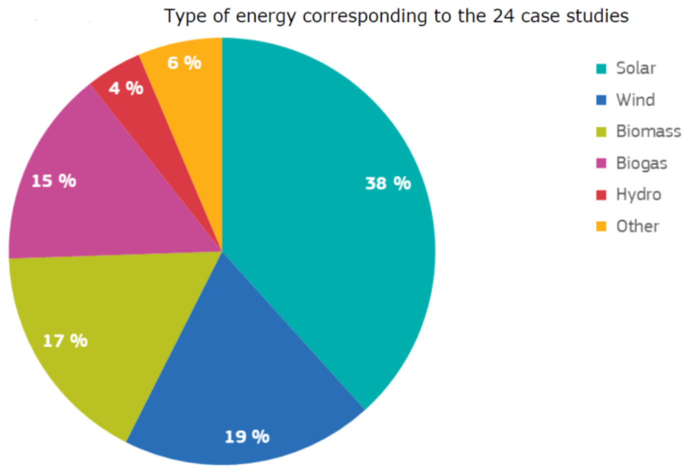

Figure 2-2: Type of renewable energy identified among case studies (source: Caramizaru and Uihlein, 2020)

Besides solar energy, onshore wind energy is also an important technology for energy communities. Especially in Germany, Belgium, France or the UK, there are many cases of community-owned wind turbines (Caramizaru and Uihlein, 2020). However, this applies mainly to rural areas (the background study in chapter 3 will mention case studies). In relation to urban areas, energy communities focusing on wind energy are hardly mentioned and wind resources in the urban environment remain generally underexploited. Theoretically, however, technologies such as building-mounted turbines could become more relevant in the future, as specific turbines have already been designed that have low start-up speeds and a lower rated power (Adam et al., 2016).

The study of the JRC also found examples of biomass community-owned schemes in Denmark, Sweden, Germany, Poland and Belgium, engaged in the production of heat from wood fuel, for example. The cooperative Som Energia has inaugurated the first biogas plant in Spain (Caramizaru and Uihlein, 2020). Moreover, the RED II supports the promotion of biomethane as an option for RECs.

Particularly three named technologies – solar PV, onshore wind and biomass heating – are the most relevant options for community projects. Their advantages include modularity, maturity, simplicity or the availability of providers of technical services. Other renewable energy technologies that require large investments, such as hydro-electric power production, geothermal energy or offshore wind power, are less attractive for community energy projects (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018).

Although solar PV is the most common energy form used in energy communities, Lazdins et al. (2021) also name some disadvantages, which are mainly associated with the question of whether the respective contextual factors are favourable (s. chapter 2.5). The authors mention aspects such as limited rooftop area or low PV penetration in some areas (especially in the Northern Hemisphere) and argue that the best option for a local energy community would be hybrid power generation, including solar energy. As a frequently mentioned issue of renewable energy is its variability on a temporal scale, it is often found that the complementarity of a portfolio of different renewables can improve the volatility (Lowitzsch, Hoicka and van Tulder, 2020).

2.6.1.2 Technical design

Several dimensions need to be considered for the technical design of a local energy community. Tounquet et al. (2019) identified three different technology layers for energy communities, displayed in **figure 2-3**. Of course, the configuration with respect to these elements depends largely on the specific context of the local energy community and might also be expanded over time. For example, an energy community might or might not opt for a storage system.

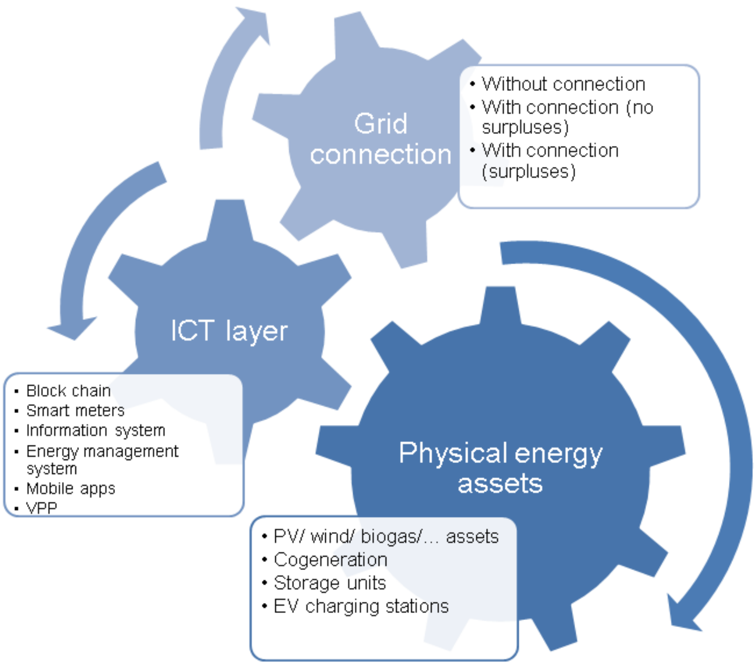

Figure 2-3: Technology layers of energy communities (based on: Tounquet et al., 2016)

The three dimensions are explained in more detail in the following.

Layer 1: Physical energy assets:

Based on the chosen distributed renewable energy resource (see previous chapter) and other aspects (e.g. storage), different physical energy assets need to be installed including solar panels, cogeneration systems, batteries or electric vehicle (EV) charging stations.

- *Energy generation assets*:

Regarding the physical assets for energy generation, such as PV panels, different choices need to be made. Since solar PV is currently the most relevant technology for energy communities and therefore also at the focus of the case study in chapter 4, a few technical characteristics and installation configurations to be considered in the design for this specific technology are mentioned in the following (Fakhraian et al., 2021):

- PV technology, e.g. crystalline silicon
- Peak potential [kWp]
- System loss [%]
- Mounting position (free-standing or building integrated)
- Tilt angle with the horizontal (defines the solar radiation reaching the surface)
- Row spacing
- Thermal gaps
- Geographic potential

The PV panels, which transform the sunlight into direct current, are connected through the wiring of the installation to the inverter, which transforms the direct current into alternating current and monitors the generation of the electricity. Moreover, a generation meter must be installed, so that the production can be counted and distributed among the associated consumption points. Most existing meters are compatible with PV installations. **Figure 2-4** shows the conceptual design of a PV installation in an energy community.

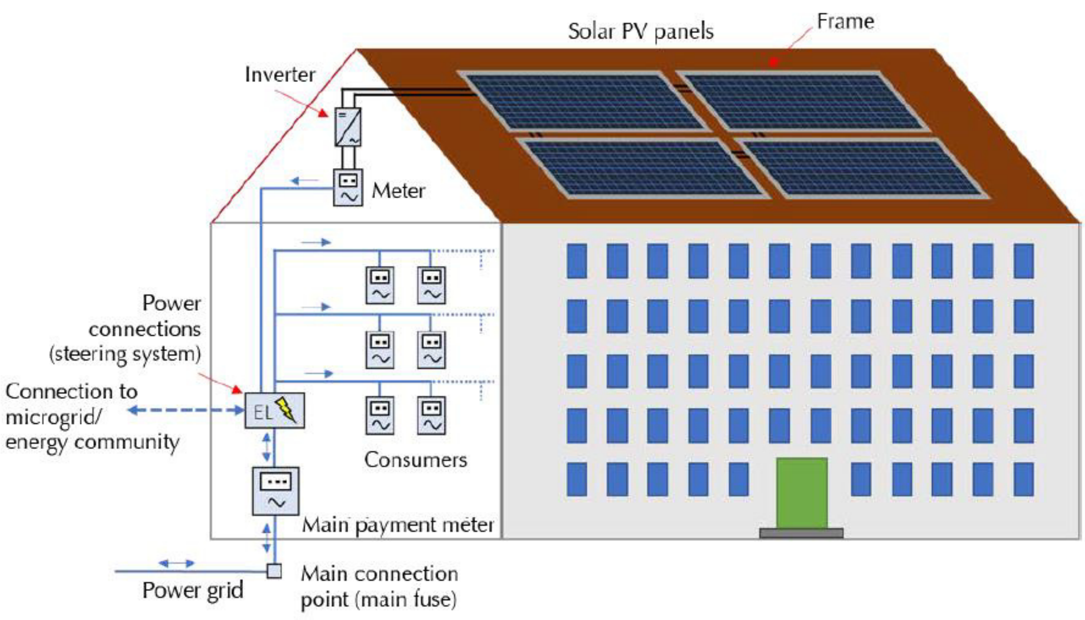

Figure 4 - Conceptual design of a PV installation in a energy community

Figure 2-4: Conceptual design of a PV installation in an energy community (Energiforum Sydhavn, 2020)

There is a variety of online tools available for rooftop PV design, such as K2Base, described in the methodology and used for the case study. The technical potential can be defined as the “maximum electricity production by transforming the solar energy received by the available roof area into electrical energy considering the technical characteristics” (Fakhraian et al., 2021). The technical potential for a certain configuration and location can be calculated with the help of solar databases such as PVGIS.

- *Cogeneration systems*:

Although most studies focus on electricity networks, cogeneration systems are also an option to be considered, depending on aspects such as scale of the project, investment capability etc. These systems imply the simultaneous generation of different energy vectors, e.g. combined power and heat systems (Comodi et al., 2019). Braeuer et al. (2022) recommend a design with multi-energy forms, integrating electricity, heat, and electric mobility, as it offers high efficiencies, higher reliability and the possibility to integrate a higher share of renewables.

- *Storage units*:

Due to the intermittence of some renewable resources, such as solar or wind, a storage system can be considered. Its purpose is to “store and deploy variable energy as dispatchable generation during periods of high demand in an electrical grid” (Lowitzsch, Hoicka and van Tulder, 2020). The surplus electricity stored can then be discharged e.g. during night time, leading to a reduction of the electricity that needs to be withdrawn from the grid. Also, energy storage allows consumers to engage in the electricity market. A commonly used technology is a lithium-ion battery (Bartolini et al., 2020).

A single energy storage system can potentially serve multiple consumers. **Figure 2-5** features a possible configuration of an energy storage system, as possible for the case of an energy community. The community energy storage (CES) can be charged with local renewable generation or procured from the grid. It is assumed that a central coordinator coordinates the charging and discharging and each building has a net meter for monitoring of energy flows.

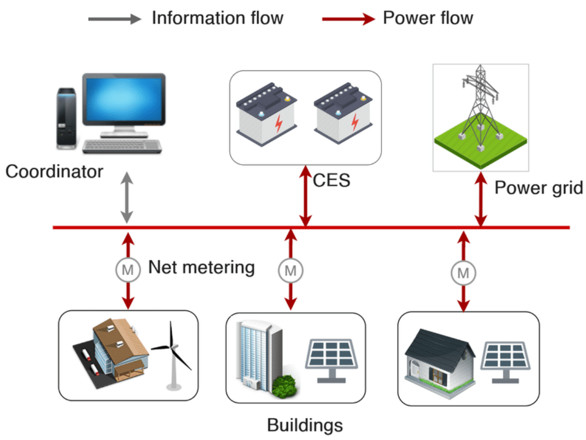

Figure 2-5: Possible energy storage system for an energy community (Yang, Hu and Spanos, 2020)

- *Electric vehicle (EV) charging stations*:

Depending which activities the energy community chooses to engage in, other physical assets may be necessary, such as EV charging stations. The vehicle-to-grid (V2G) technology allows car batteries to transmit power back into the grid. The inclusion of EV services in an energy community therefore also increases flexibility and the self-consumption rate by making use of the produced excess electricity (Caramizaru and Uihlein, 2020).

Layer 2: Information and communication technologies (ICT)

The availability of data plays an important role in the optimization of energy communities, both in the design phase (e.g. to estimate the dimensions of local energy flexible resources, for example battery-inverter systems) and in the operational phase (to manage local flexibility and increase energy efficiency and self-consumption). Especially in energy communities with a higher number of assets and connected consumers, information and communication technologies (ICT) – or: the virtual layer - allow controlling the elements of the physical layer as well as monitoring and evaluating data on production, consumption or savings etc. (Kazmi et al., 2021).

ICTs include for example: block chain, smart meters, information and energy management systems or mobile apps. Smart meters (**figure 2-6**) are often mentioned as an important technology in this context, but it strongly depends on the current status of the roll-out whether this is an option. Art. 2 pt. 23 of the EU IEMD defines smart meters as: “an electronic system that is capable of measuring electricity fed into the grid or electricity consumed from the grid, providing more information than a conventional meter, and that is capable of transmitting and receiving data for information, monitoring and control purposes, using a form of electronic communication”. This allows analysing and optimizing the balance of production and consumption (Lowitzsch, Hoicka and van Tulder, 2020). A smart meter measures energy consumption in the same way as a traditional meter, but has communication capabilities allowing the data to be read remotely and displayed on a device inside the home or transmitted securely outside. It is usually placed at the boundary point between the consumer-owned receiving installation and the distribution network connection, owned by the distribution network operator (IDEA, 2019).

Figure 2-6: Smart meter (Centre for Sustainable Energy, 2013)

An increased digitalisation, e.g. through mobile apps that visualize energy activities, can also facilitate member participation and engagement. Otamendi-Irizar et al. (2022) note that all digitized data shall be available open source and transmitted to the entire population affected, as this promotes awareness and increases transparency.

The blockchain model refers to a digital contract that enables the sharing and sale between members of a community of the electricity produced by their PV installations without any intermediary interfering (peer-to-peer trading). It is already being implemented in first energy communities, for example in the Netherlands (IDAE, 2019). Virtual power plants also facilitate the aggregation of distributed generation and flexibility of local energy communities and enables them to get engaged in distribution, management or trading of energy (Summeren et al., 2020).

Layer 3: Grid connection

A classification of energy communities can also be made based on their grid connection. Energy communities can be on-grid or off-grid ("isolated"), meaning that there can be an exchange with the main distribution grid or not.

Energy communities may cross boundary properties and form a microgrid, which can be defined as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid" (Lowitzsch, Hoicka and van Tulder, 2020). Next to the possibility to exchange electricity through an own grid, energy communities can make an agreement with the local network company. **Figure 2-7** shows outline of the electricity grid with different buildings of an energy community.

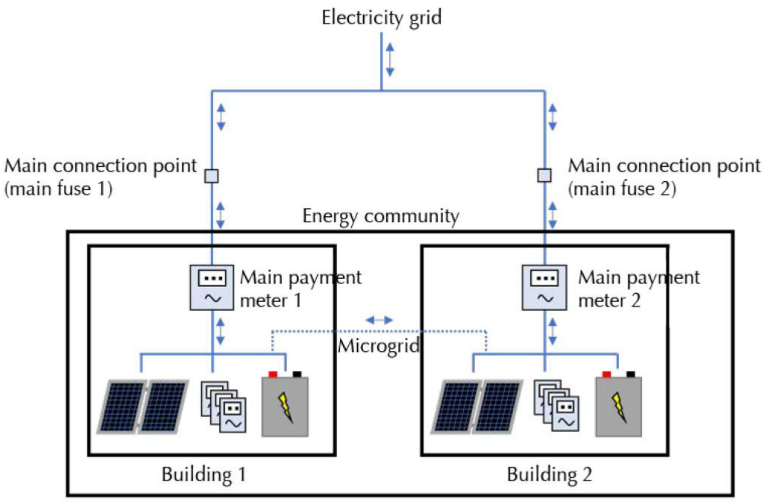

Figure 2-7: Electricity grid with multiple buildings in the Energy Community (Energiforum Sydhavn, 2020)

The generated energy is distributed among the community members according to distribution coefficients between 0 and 1 (with the sum of all coefficients being 1). The Spanish government is committed to introducing dynamic distribution coefficients in the near future, where the coefficient may vary throughout the day, taking into account the respective demand at a given moment.

Members of an energy community can be connected physically or virtually. In the latter case, they are simply connected to the same general network, which is the national electricity system. An example for a physical connection is a low voltage grid to which members are connected and an example for a virtual connection is a set of members who perform an aggregate purchasing action of electricity. It is important to consider that in case of virtually connected community members, it is not possible to include thermal energy supply in the model, both at building level or in a heating or cooling network (IDAE, 2019).

2.6.2 Organizational aspects

2.6.2.1 Legal form

In chapter 1.3 it was already mentioned that energy communities imply the establishment of a legal entity, which is not necessarily the case with mere self-consumption. It was also explained that in EU and Spanish national legislation no specific legal form is mandated.

The following list gives an overview of the different legal forms for energy communities mentioned in reviewed publications (Capellán-Pérez, Campos-Celador and Terés-Zubiaga, 2018; Caramizaru and Uihlein, 2020; Gjorgievski, Cundeva and Georghiou, 2021; Hoicka et al., 2021):

- **(Energy) cooperatives** (autonomous association of people to collectively own and manage renewable energy projects)
- **Limited partnerships** (governance is usually based on each member's share)
- **Associations** (voluntary association of natural and/or legal persons in pursuit of a specific objective)
- **Community trusts and foundations** (generate social value and local development, rather than benefits for individual members)
- **Housing associations** (non-profit associations addressing tenants in social housing; they are not necessarily directly involved in decision-making; relevant for energy poverty)
- **Non-profit customer-owned enterprises** (legal structures to manage independent grid networks, e.g. for community district heating networks)
- **Public-private partnerships** (agreements between local authorities and citizen groups and business to ensure energy provision or other benefits for the community)
- **Public utility company** (run by municipalities, investing in and managing the utility)

In the recent years, solar PV cooperatives have become increasingly prominent and as of 2021, there were about 3500 renewable energy cooperatives in Europe (Gjorgievski, Cundeva and Georghiou, 2021). In this case, it is mainly the members who benefit from the ownership structure, as surpluses are reinvested to support the members and the community (Caramizaru and Uihlein, 2020). Capellán-Pérez, Campos-Celador and Terés-Zubiaga (2018) name cooperatives and municipal utilities as the two most common collective alternatives to traditional ownership and mention that Spain has a lack of tradition in municipal utilities. Two types of entities that can be observed in many energy community projects in Spain are “*cooperativas*” and “*asociaciones*”.

Hoicka et al. (2021) have compared cooperatives, trust schemes and limited partnerships with respect to their compliance with RED II aims. They conclude that while cooperatives and trust schemes are eligible as RECs, involve members in decision-making and generally comply with the criteria of inclusiveness, limited partnerships may violate the autonomy criterion and offer restricted control rights for consumer-shareholders. On the other hand, Caramizaru and Uihlein (2020) note that limited partnerships can be suitable for large projects with a high investment volume.

2.6.2.2 Actors

It is important to define, map and understand the group of actors, both in terms of potential members and in terms of relevant external partners and stakeholders. The following actors are mentioned frequently in connection with local energy communities (Gjorgievski, Cundeva and Georghiou. 2021; Otamendi-Irizar et al., 2022):

- Consumer/ prosumer
- Producer
- Energy community manager or core group
- Local authorities/ administration
- Citizens not involved in but affected by the project (e.g. neighbours)
- Academics
- Investors
- Marketers (“*comercializadora*”)
- Distribution and transmission grid operators
- System operators

According to the EU directives on energy communities, RED II and IEMD, shareholders and members can be: natural persons, local authorities including municipalities or enterprises. Individual members should retain their rights and obligations as individual actors (for example, to change the supplier if they wish), but at the same time be able to act as a collective entity (Gjorgievski, Cundeva and Georghiou, 2021).

Moreover, a distinction is made between consumer, producer and prosumer: While the consumer is simply connected to the grid consuming energy and the producer is connected to the grid producing energy, the prosumer combines both roles. Moreover, some prosumers who have controllable assets might be capable of offering flexibility (Tounquet et al., 2019).

Gjorgievski, Cundeva and Georghiou (2021) have subdivided possible internal actors of energy communities into the following groups (**figure 2-8**): **initiators** (set in motion the community project and therefore play a crucial role; they might or might not be beneficiaries), **energy services providers** (any actor that provides energy-related services, such as generation, distribution, supply of energy or related commodities, storage, installation and maintenance, or aggregation) and **consumers** (beneficiaries of an energy commodity or service). However, an actor might adopt more than one role within the community and in some cases a certain energy service provider might be internal, while in others external.

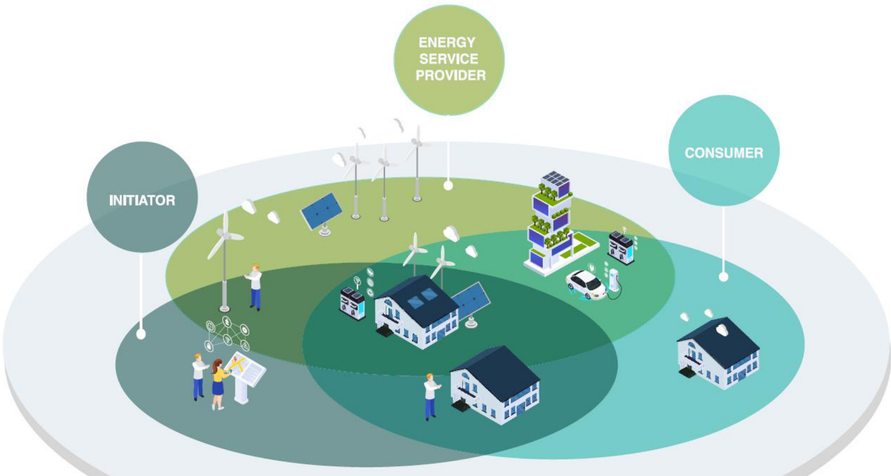

Figure 2-8: Actors within an energy community (Gjorgievski, Cundeva and Georghiou, 2021)

With respect to external actors, it is important to mention local authorities. Generally, energy communities can be initiated both as bottom-up or top-down communities, but it can be said that many successful cases involve the support of and collaboration with municipalities and local authorities. The contributions they can make are manifold, such as related to financing, sharing of municipal staff and resources, development of platforms and tools, facilitation of the dialogue among local stakeholders, promotion of favourable regulations or awareness raising (Walsh, Castanié and Giovannini, 2020). Also, they are particularly relevant in case of installations on public buildings, e.g. rooftop PV. Of course, they can also become a direct member of the community.

2.6.2.3 Engagement and governance

Important aspects of governance of energy communities are: eligibility of members or shareholders; primary purpose; membership (conditions); ownership and control; decision-making; engagement and collaboration; distribution of benefits.

According to the EU directives RED II and IEMD, RECs and CECs must be based on open and voluntary participation, and must be effectively controlled by its shareholders and members. Regarding ownership and control, the RED II directive stipulates that the community should be effectively controlled by the shareholders or member that are located in the proximity of the project and that it should be autonomous, i.e. no single shareholder may own more than 33% of the stock (Hoicka et al., 2021).

As community ownership is one of the main motivations for developing energy community projects, participation and decision-making is a key governance element. The decision-making spectrum defined by Hicks and Ison (2018) ranges from “one vote per actor” on to “one actor has all votes”. Projects that emphasize participation in decision-making and equality should therefore choose the “one vote per actor” principle. This is the case for example in cooperatives, as they are based on democratic governance (Caramizaru and Uihlein, 2020). Hicks and Ison (2018) point to specific community energy cases where initiators considered this principle unsuitable, for example projects associated with significant capital investments. In some of these cases, a company structure was implemented to boost investor confidence and provide investors with decision-making power reflecting their adopted risk, although measures were taken to ensure local participation, such as the definition of a maximum share by any shareholder.

Otamendi-Irizar et al. (2022) give the following recommendations related to governance of local energy communities:

- For the **start-up and the engagement process**, it is recommended to set up a multidisciplinary team to take into account the diverse dimensions of a local energy project and to follow established methodologies in the engagement process, such as Living Labs, in cooperation with local administrations.
- The model of governance should be based on **collaboration and citizen power**, moving from a collective approach to a collaborative approach (collective action is the result of aggregating individual efforts, but not necessarily with a common goal and effort, while this is the case for collaboration).
- Develop a **hybridization between bottom-up and top-down models** (collaboration between public administration, local business and the university).
- A “**polycentric governance model**” is characterized by local action, consideration of local conditions, experimentation and learning, trust as well as self-organisation, and therefore considered particularly suitable for local energy communities.

2.6.2.4 Activities communities can engage in

Energy communities can focus on activities directly related to the field of energy, or adopt a more integrative approach, conducting activities such as educational programmes. Also, services in the field of electric mobility are becoming more popular. For example, the Spanish cooperative Som Mobilitat rents parking spaces in cities and offers electric car sharing services (Caramizaru and Uihlein, 2020). The following activities were named in different publications (Frieden et al., 2019; Caramizaru and Uihlein, 2020; Gjorgievski, Cundeva and Georghiou, 2021; Otamendi-Irizar et al., 2022):

- **Energy generation** (collective use or ownership of generation assets)
- **Supply** (sale/ resale, e.g. of excess electricity)
- **Distribution** (transport of electricity on high-voltage, medium-voltage and low-voltage distribution systems, excluding supply)
- **Consumption and sharing**
- **Energy services** (e.g. energy efficiency or energy saving measures, flexibility and storage; energy monitoring and management for network operations)
- **Electric mobility** (e.g. car-sharing or charging stations)
- **Consulting activities** (e.g. for the implementation of energy community projects)
- **Information and awareness-raising campaigns** (e.g. educational programmes)
- **Environmental conservation actions**
- **Urban regeneration projects**
- **Fuel poverty measures**

The majority of local energy communities are engaged in the generation and sales of energy (Otamendi-Irizar et al., 2022). Capellán-Pérez, Campos-Celador and Terés-Zubiaga (2018) recommend renewable energy cooperatives in Spain to diversify their activities, both within the electricity sector (for example, distribution activities or electric mobility) and through extending to other energy markets, such as heating or cooling production and distribution. This corresponds to “Technological scaling” (asset/ infrastructure expansion or use-case diversification), according to **figure 2-1**. Romero-Rubio and Andres Dias (2015) analysed opportunities for activities for energy communities in Spain and mention further areas, which are not addressed very much by communities so far, such as:

- **Efficient district-heating/ cooling networks**: In case of smaller networks, e.g. supplying a small group of buildings, consumer or owner associations could be involved.
- **Production and commercialization of biofuels:** There are about 4000 farming cooperatives in Spain, who could diversify their activities by engaging in the production and commercialization of biofuels, thereby also contributing to the achievement of goals related to the share of renewables in transport.

To sum up, local energy communities can be classified with respect to activities according to their level of comprehensiveness: less comprehensive projects are rather limited to the field of energy (e.g. energy generation, energy saving), while more comprehensive projects adopt an integrative vision addressing more lines of actions going beyond activities strictly linked to energy (e.g. educational programs, environmental conservation actions, improvement of public spaces, agri-food, social contribution). Energy communities tend to diversify their activities as they consolidate and grow (Otamendi-Irizar et al., 2022).

3 Background study on energy communities

"(…) *it is essential to be aware of existing projects in order to identify best practices and the keys that have enabled some organizations to achieve results beyond the field of energy* (…)."
(Otamendi-Irizar et al., 2022)

3.1 Characteristics of the contacted energy communities

A survey was conducted among existing energy communities in Spain. In total, 33 energy projects were contacted, of which 17 (52 %) either sent back the questionnaire directly or offered to clarify the questions via a phone call. These projects are included in the evaluation as "verified" data, while the remaining energy communities were included as "unverified", based on the information collected online. In case of projects that are still in the initial phase, the corresponding characteristics as planned have been included. Most communities are located in smaller cities or a rural environment.

3.1.1 Organizational characteristics

As the establishment of a legal entity represents the basis for RECs or CECs under EU legislation, the respondents were asked to indicate their organizational form. As can be seen in **figure 3-1**, most of the projects, both verified and unverified, have chosen the cooperative form of organisation. This underlines the information identified in the literature review that cooperatives are among the most common forms for energy communities. In addition, there are associations and a limited partnership.

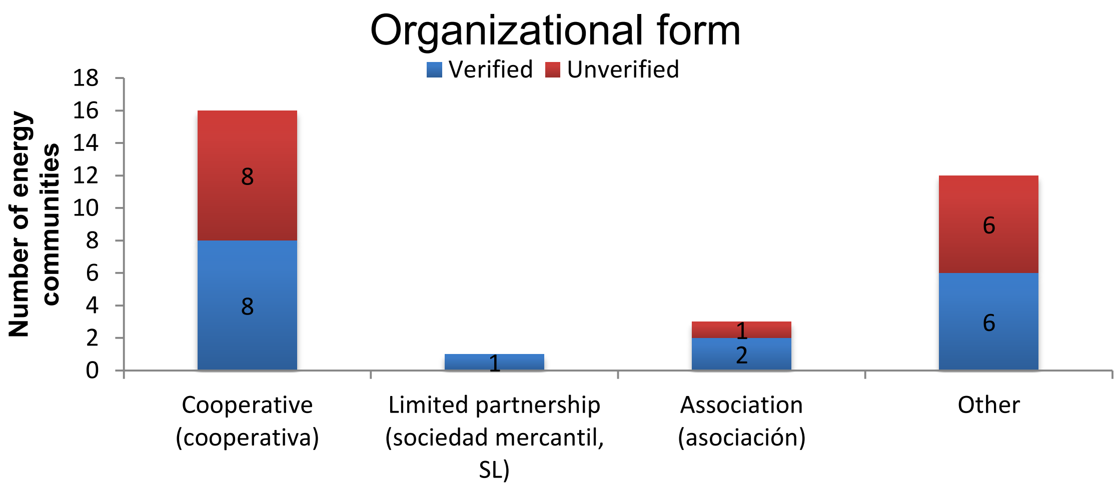

Figure 3-1: Organizational form of reviewed energy community projects (own elaboration)

In addition to the specified organizational forms, there were several other indications that do not all necessarily correspond to a legal entity: public-private-citizen partnership; community/ municipality; local initiative; agreement between the city council, a non-profit organization and a utility company. The latter is the "*Barrio Solar*" in Zaragoza, which also does not specifically describe itself as a local energy community, but has many relevant characteristics. There is also a case where the participants of the energy community are members of an overarching cooperative including different communities and projects, but within the cooperative they do not have their own organizational entity.

Another important component of the organizational structure is the opportunity for members to directly participate in decision-making (**figure 3-2**).

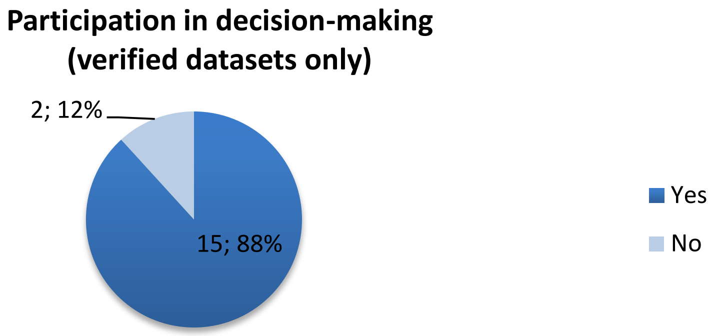

Figure 3-2: Participation in decision-making (own elaboration)

In 15 of the 17 verified projects (88%), this condition is met. Only in two projects is this not the case. One of these is the "*Barrio Solar*", which, however, as mentioned, is not specifically a local energy community. The free decision of each individual in this case is to join or leave the community.

3.1.2 Stakeholders

The stakeholders mentioned by the energy communities that returned the questionnaire can be summarised according to the following groups: **citizens involved as members**; members of the **core group**; **third-party citizens** (e.g. other neighbours, non-member citizens involved in activities); **local public authorities** (e.g. city council, AMB, City Council Energy Office); **SMEs/ local businesses** (e.g. shops, businesses, bars, companies that are tenants of the buildings of the community); engineering companies/ consultancies (e.g. installers); **marketer** ("*comercializadora*"); **educational institutions** (e.g. school council); **associations** (e.g. local parents' association ("*asociación de madres y padres*") or neighborhood association); **other organizations** (e.g. Greenpeace, Som Energia). Regarding the core group, in case of the "*Alumbra*" energy community it was highlighted that it represents the diversity of the village and includes e.g. the city council, individuals, associations, businesses etc.

3.1.3 Activities

As already described, a distinction can be made between more or less comprehensive projects, whereby the latter tend to be limited to the field of energy, while the former include also activities not strictly linked to energy, such as educational programs or the improvement of public spaces. **Figure 3-3** shows that the activities of most communities are focused on energy-related activities, primarily energy production and consumption. The energy communities that did not indicate energy production as an activity were generally consumer cooperatives ("*cooperativa de consume*"), for example offering renewable energy as marketer ("*comercializadora*") at a reduced price for members. Likewise, one of the verified communities did not report energy consumption as an activity. This is the project "*Viure de l'aire*", which focuses on wind energy, where a lack of regulation does not allow the disposal of the electricity generated, so it is sold on the wholesale market and the benefits are then distributed among the members.

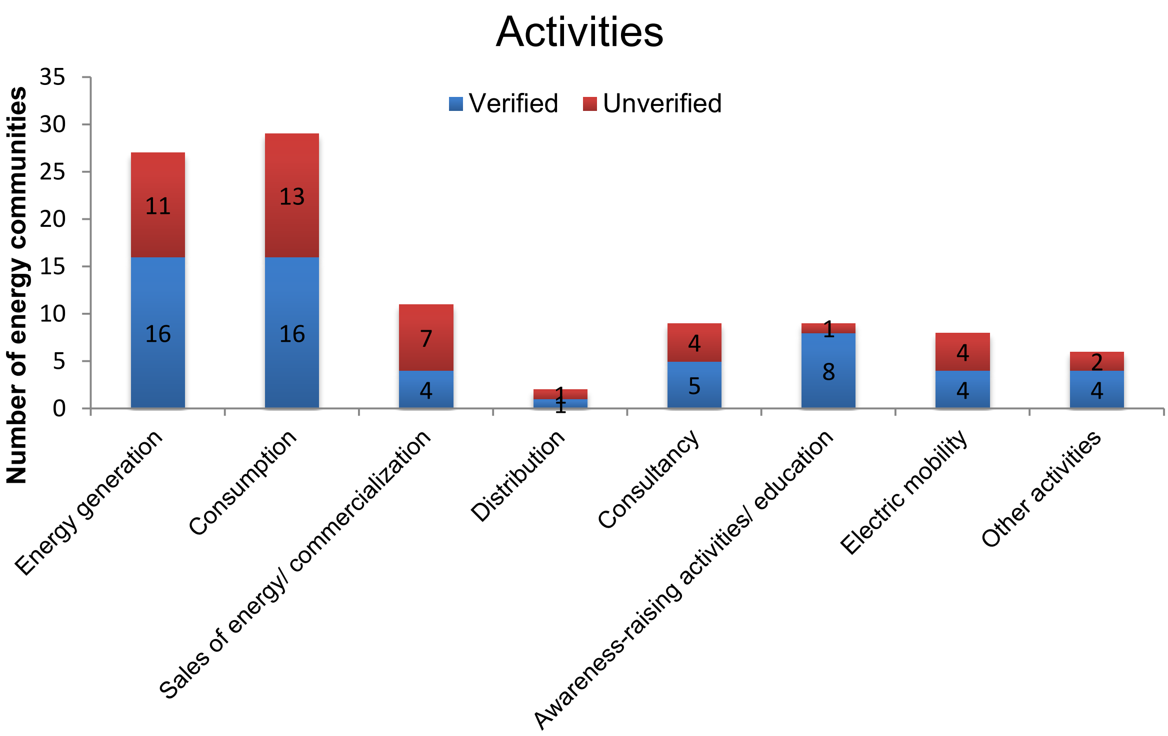

Figure 3-3: Activities of the energy community projects (own elaboration)

Most of the verified energy communities focus on either two or three activities in parallel, while the highest number of different types of activities registered is seven (in case of the project "*Vilawatt*"). Consultancy fields include consumption (billing, opportunities for improvement, responsible contracting, energy efficiency, self-consumption); advice on setting up energy communities or pilot projects that can be replicated in other neighbourhoods; as well as energy audits. Under "other activities", the listed projects included measures to combat energy poverty (e.g. solidarity scheme of "*Barrio Solar*", where a share of the energy goes to families in energy poverty without them having to pay any monthly quota); collective analysis of generation and consumption; the implementation of an app to learn how to save on bills or adjust consumption; flexibility of energy consumption; energy rehabilitation of buildings or activities in urbanism, such as tree planting.

An example of a project integrating different lines of activities is the energy community "*Alumbra*" in Huelva (where more detailed information was collected in an interview). The first pillar in the energy community project is the energy generation with a PV installation on the roof of a school (sub-project "*La energía del cole*" launched together with Greenpeace). The consumers will be families in the neighbourhood and the school itself will also self-consume part of the electricity. Moreover, the project is understood as a "learning community" and conducts an energy literacy programme, where families, companies etc. will learn to analyse their energy demand or to improve the efficiency in their consumption. In the future, it is planned to set up more generation projects and offer further services, such as possibly electric mobility.

3.1.4 Energy technology

The study also reflects the fact that solar energy, especially PV, is generally the most frequently chosen energy technology for energy communities due to advantages such as modularity or simplicity. In case of one project it is stated: "We started with photovoltaic because it is very scalable but we do not rule out other technologies in the future."

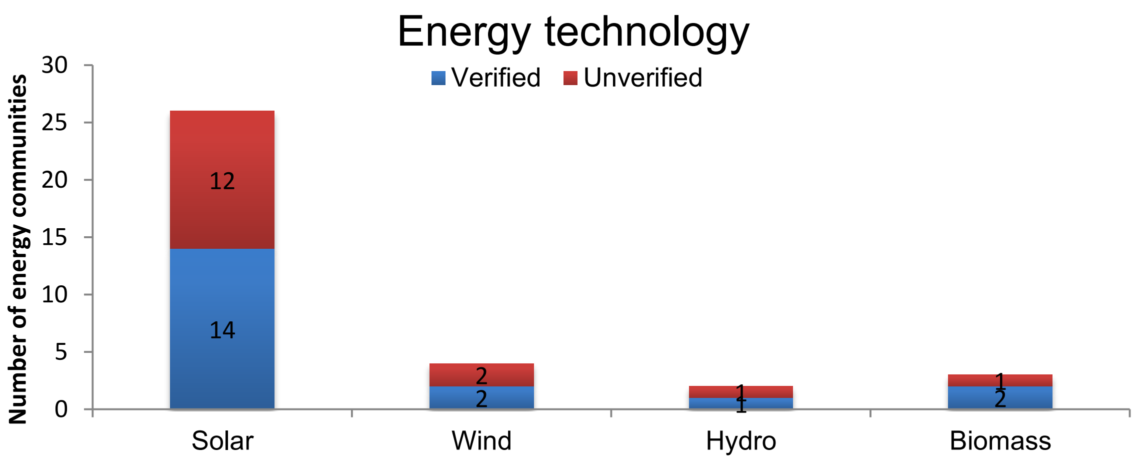

Figure 3-4: Installed energy technologies for power generation (own elaboration)

In several questionnaires the location of the solar PV installations was also mentioned, for example on the roofs of municipal centres, sports centres, private houses and schools, or installed as a solar park on a plot of rural land.

As displayed in **figure 3-4**, there are also examples of wind energy, such as the mentioned project "*Viure de l'aire*" or another project envisaging the installation of mini wind turbines in industrial areas. Other technologies applied by individual projects include hydro energy (for example, a minihydraulic power plant in case of the project "*Gares Energía*") or biomass projects. In the latter case, one is a "classic" energy community, and the other example is not an energy community in the narrower sense. It is the project "*Vinyes x Calor*" in Vilafranca del Penedès, a local initiative focusing on the use the biomass resulting from the pruning of vines in vineyards to obtain energy to supply a range of public and private heating and cooling systems. The project has been led by the Vilafranca Town Council and brings together the Innovi wine cluster and two local cooperatives. It is a good example for the feasibility of local multi-party management of energy self-sufficiency (IDAE, 2019).

3.1.5 Installed potential and annual generation

The following graph (**figure 3-5**) shows the installed potential of the verified energy communities with solar PV. In total, six of the projects have an installed potential of less than 50 kWp, seven projects have a potential between 50 and 100 and one project has a potential of 210 kWp. Some of the values given add up different installations of an energy community. Also, some installations are only in the planning stage.

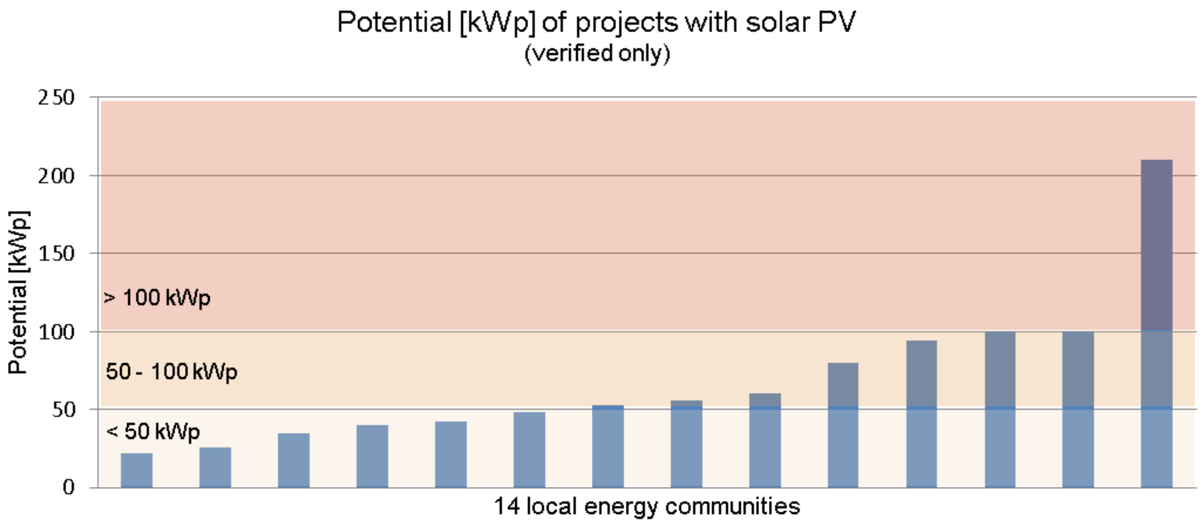

Figure 3-5: Solar PV potential of verified projects (own elaboration)

Not all questionnaires indicated the annual production. In these cases, the value was estimated based on the potential with the PVGIS tool. The (estimated) annual production of communities with a potential of less than 50 kWp ranges between 22’020 kWh and 71’550 kWh, the (estimated) production of projects with a potential between 50 and 100 kWp ranges from 91’984 to 150’000 kWh and the community with a potential of 210 kWp has an estimated annual production of 293’776 kWh. A higher potential does not necessarily lead to a higher production, due to different location-specific factors influencing the yield, such as solar radiation, azimuth or inclination.

The turbines of the two projects that produce electricity with wind energy have a potential of 1’000 kW and 2’350 kW respectively. For the latter one, a production of 5’653 MWh per year was indicated. In the biomass project, two boilers with a total of 630 kW were installed, generating thermal energy.

3.1.6 Surplus

The questionnaire included the following question: “What happens to surplus energy produced (e.g. compensation, storage, sales)?”. The answers given by the 17 energy communities that participated in the survey can be summarized with the following categories:

- No surplus
- Sales
- Compensation (“*compensación (simplificada)*”)
- Storage
- Community-benefit

In two cases it was stated that no surplus is generated: once in a project based on thermal solar energy, and in the other case the amount of energy received by each neighbour is relatively small and therefore no surplus is generated. In the case of the mentioned project “*Viure de l’aire*”, all of the energy generated is sold to the wholesale electricity market.

In total, nine projects have chosen (simplified) compensation or are planning to do so once the project is active. This implies, for example, discounting the energy fed into the grid at a price that will be updated quarterly. For one project, a study was commissioned on whether it is better to offset or sell surpluses and although the study is still ongoing, everything so far points to compensation.

One project has a storage system in place (batteries with a storage capacity of 57.4 kWh) and in case of at least two further projects it is planned to implement this in future. In one questionnaire it was noted that storage is a key element in future energy management, especially when the main source is solar PV energy.

There were two special cases, where the surplus is used for the general benefit for the community. In one case, the answer was that the surplus is destined to families affected by energy poverty. In the second of these special cases, 34% of the energy is used for the town hall building, which houses the doctor's surgery, the pharmacy, the pensioners' club, the cultural centre and the headquarters of a Community Association, as well as for the school and sports facilities. The surplus will be fed into the grid for the community's own consumption and the whole neighbourhood is called upon to benefit from it.

3.1.7 Financing

As already mentioned, the focus of this master thesis is on the organisational and technical aspects of energy communities. Nevertheless, as a matter of completeness, the financing mechanisms were included in the questionnaire. The most relevant named mechanisms were member contributions or shares, support of a local authority as well as subsidies.

3.2 Learnings and best-practices of the energy communities

3.2.1 Challenges

The main challenges named by the energy communities can be summarized as follows:

- **Lack of a clear regulatory framework**. This includes a lack of clear frameworks and agreements for relations between different public institutions and citizens at local and regional level. Moreover, at the local level, facilitating frameworks are required (e.g. for the cession of public spaces, facilitation of the development of local energy communities). At regional level, the frameworks for a true sustainable development (cohesion and territorial planning, safeguarding of natural spaces etc.) are named as often insufficient.
- **Shortcomings of the current regulation**, such as regarding a static allocation as well as the limit of 500 m between production and consumption point, or a limitation to 100 kW.
- **Decision about the distribution criteria**.
- **Administrative and bureaucratic hurdles**, for example deadlines for the implementation in order to be eligible for subsidies.
- **Procedures with external agents, such as the marketer or the distribution company**, are often cited as one of the main challenges. This includes procedures imposed by the distributor for connection, self-consumption or invoicing, and is made even more complex by the fact that in most energy communities not all members have the same marketer.
- **Lack of information**, such as the access to energy data.

- The **engagement of members** is cited as a challenge, exacerbated by the usually high reliance on voluntary work. Local energy communities require active citizen participation in highly normalized sector.

3.2.2 Success factors and best-practices

Some success factors were mentioned in the questionnaires and further best practices were identified during the review of the energy communities. The main aspects are:

- **Cooperation with public administrations**, such as with the establishment of joint working spaces between public administrations and the population. Talks with local councils to see what formulas can be used to make municipal roofs available for uses linked to the energy transition are important (there are very valid models, such as calls for tender for the transfer of roofs or collaboration agreements). For example, the cooperation with the city's energy office is mentioned as a success factor in one case.
- A great effort must be made in terms of **information and training**, including topics such as the clarity of billable concepts or energy training for citizens. A clear communication is important, especially in translating technical aspects to people who are not experts in the field. This applies to energy communities, because open participation is a precondition and people beyond those who are highly motivated and with prior knowledge should be reached.
- **Seeking expert advice** where required is also important, for example energy advice, legal advice or advice on participatory processes. It was stated in one questionnaire that it is recommended to have a qualified and motivated driving group and, beyond that, ask for collaboration with other entities with experience.
- The **collaboration with neighborhood movements** is another success factor mentioned.
- **Open-data and exchange among energy communities**. One of the energy communities mentioned that they have their statutes made available in the hope that it will be easier for future cooperatives to develop. Information-sharing can pave the way for new communities as they can replicate aspects, for example in terms of contractual issues, internal regulations or organization.

3.2.3 Potential for improvement

In addition, some communities indicated aspects they would like to improve:

- **Diversify energy sources**, for example mini-wind or solar thermal, and consider cogeneration.

- Increase the **installed capacity** and strengthen the energy generation. Raise capital to undertake investments in renewable generation in order to be self-sufficient.
- Greater **participation** of the community members.
- Establishment of **increased relations between the neighbors** of the base community so that they can articulate collective and consensual objectives in the fight against climate change.
- **Streamline the procedures**.
- In case of biomass, obtain a **quality label**.

3.3 Key learnings from expert interviews

The results from the expert interviews are presented below according to topics discussed with the interviewees.

3.3.1 Framework conditions for the implementation of local energy communities

3.3.1.1 Framework conditions in Spain

With regard to the general framework conditions for energy communities in Spain, many interview partners mentioned the lack of a clear legislative framework and an insufficient transposition of the European directives [IP1, IP3, IP4, IP8]. This creates the paradox that subsidies for the promotion of local energy communities are being approved without having sufficiently regulated what exactly an energy community is [IP4]. One of the main problems mentioned here is that there is no concrete legislative framework that allows the communities to be constituted as such, gives them legal certainty and includes precautions that grant them competitive advantages compared to other actors of the energy sector. Beyond for instance aids or setting up a network of energy transition offices, a regulatory framework that gives energy communities competitive advantages over other actors, such as a normal marketer ("*comercializadora*"), would be essential [IP3]. According to IP8, no specific legal figure for energy communities needs to be defined, but projects should be able to select from a range of legal forms. IP3 further points out that it should be made more concrete in the legislation that citizen communities can operate e.g. in generation, supply or even distribution.

In addition to the lack of a clear legislative framework, drawbacks about the existing legislation were mentioned. An important aspect is the maximum of 500 m between the point of generation and consumption, which hinders the development of energy communities in many cases. For example, IP3 points out that the limit creates problems for large cities or regarding the interaction between industrial parks and cities. There is usually a long distance between industrial parks (which often have good conditions for energy generations as there are many roofs with a big surface while the consumption is low during certain time periods) and urban centres (consumption). Consequently, this interaction often does not take place due to the limit of 500 m.

3.3.1.2 Framework conditions in the Metropolitan Area of Barcelona

According to the interview with IP4, a representative of a local project, the installation of solar panels in Barcelona is associated with different hurdles. The group made a collective purchase of PV equipment and they were faced with different challenges. On the one hand, there are internal decisions to be made, such as how many panels to purchase initially, but also hurdles associated with the collaboration with the installation company or the city council. Although there have been improvements in the processes (for example, the issuance of construction permits has been streamlined), there are still bureaucratic and administrative hurdles, such as a report from an engineering school to be submitted, which takes time. The size of the municipality in Barcelona might also play a role here. Moreover, the importance of individual people and their attitude towards such projects is stressed. According to IP3, energy community projects in the Metropolitan Area of Barcelona are currently mainly driven by local councils. For example, there are projects in Viladecans or El Prat de Llobregat. The case of El Prat de Llobregat is a good example of a local energy community driven by the local city council. Five islands of self-consumption were established in El Prat, which together form an energy community.

Another aspect mentioned by IP4 is the availability and accessibility of suitable roofs for solar PV. In Barcelona, many private roofs are divided into small terraces for individual use and it can be complicated to get access to public buildings. Another possibility is a warehouse or logistics centre, which might not have a high consumption itself but has a large surface. An installation of up to 100 kW could be implemented and an agreement for shared self-consumption could be made. It is noted that it would be helpful if the local administration that has buildings could articulate in case they can be accessed for the installation of solar PV. It also remains to be seen in what legal form and to what conditions the city would cede these surfaces (e.g. concession of roofs, which could be through an announcement where different parties can apply or through a direct concession). All these aspects add uncertainty to projects.

However, IP3 said that without a response in urban areas, where we consume the most energy, no energy transition is possible. Projects in rural areas or smaller towns are not enough, there also needs to be a change of the energy system in the city.

3.3.2 Characteristics of energy communities

3.3.2.1 Energy communities vs. self-consumption

IP1 pointed out that it is important consider the characteristics that lead to energy communities going beyond mere self-consumption. Several aspects were mentioned by the interviewee, which distinguish local energy communities: a legal entity has to be formed; ownership of the members; democratic control; it should be based on a social economy model; it should be open and voluntary (so that everyone can participate, e.g. people who live in rent or have few financial resources). Also, it can go beyond mere electricity generation with, for example, PV (e.g. heat networks, collective purchasing, mobility etc.).

3.3.2.2 Scalability

One aspect mentioned by a representative of an energy community project (IP7) is the importance of scalability. Instead of focusing on small-scale (collective) self-consumption, communities in many countries, where they have been in existence for many years, have adopted new business models over time, for example, where in addition to self-consumption, energy is generated for sale. IP3 emphasizes that energy communities need a certain volume to be able to compete as an actor. This way, the concept is not only limited to optimal cases in very narrow environments, but a true transformation of the energy system can be achieved.

3.3.2.3 Location of the installation

As mentioned above, the identification of a suitable location for an installation was mentioned as a challenge by some interview partners. According to IP8, a representative of a cooperative developing different energy community projects, for instance in Valladolid, an agreement of cession with the city council for the use of a public roof is generally preferable, as in urban areas, the largest and most attractive roofs for rooftop PV installation tend to be those of public buildings. They also often have the advantage that there are not multiple owners with potentially differing purposes.

The position of PV panels is another aspect mentioned by IP4. For example, if panels are put on the ground, they take up a lot of surface that might be needed for other uses. If they are put on a pergola or above the roof, it might be denounced that additional height is gained with respect to the height allowed according to the building license.

3.3.2.4 Ownership of the installation

Related to this is the ownership of the installation. As said, the fact that the cooperative or a member owns the installation is a very important characteristic, because it truly empowers the consumer and gives more independence from traditional actors of the energy market (IP1). IP8 names two possibilities: 1) The installation is owned by the co-owners (members of the energy community), who finance it with their savings and 2) The facility is owned by the cooperative and it offers interested people the possibility to join, not as owners but as users of the facility, in exchange for an annual fee. This also simplifies the incorporation of members.

3.3.2.5 Distribution coefficient

It was mentioned by IP8 that fixed partition coefficients of the electricity produced are currently used in Spain, but that in the near future, dynamic coefficients, where the coefficient is defined after the bill has been read, could be a possibility for local energy communities. The share of the consumption that a member can cover with the energy from the energy community installation depends largely on the size of the installation, amongst other factors. Some installations are sized to cover 30% of consumption, while others are sized to cover more than 80%.

3.3.2.6 Demand-side management

IP3 points out that with an electricity mix with a large proportion of non-manageable renewables, demand and consumption management elements need to be included. Therefore, energy communities should consider offering flexibility services, demand management, shared electric mobility or other elements.

3.3.2.7 Governance

Different interviewees pointed out that voluntary and open participation are essential characteristics for energy communities (IP1, IP3, IP7). IP3 also noted that the legal concept of “effective control” should be taken into account. It is important to guarantee that the effective control of the energy community is not in the hands of a large (electricity) company. Likewise, IP7 said that transparency and participation should be honestly promoted and not mediated by large companies.

3.3.3 Further important aspects mentioned

3.3.3.1 Role of public authorities and city administrations

It became clear throughout the interviews that local public authorities and city administrations play an essential role, both in the initiation of local energy communities and as collaboration partner. City councils are important enablers, for example by making space available for installations (IP1). In Spain, the involvement of the municipalities is more complicated than in countries, where they manage in some cases the distribution network, such as in Germany

(IP3). For example, in Munich, the distribution network is in the hands of the municipality. IP3 mentioned the case of Crevillent, Alicante, where the organization Enercop is the distributor, which gives them an extraordinary advantage. The revenues also provide money for new projects. But in most cases in Spain, the grid is in the hands of a big electricity company instead of the municipality.

3.3.3.2 Role of marketers

As mentioned, the coordination with marketers ("*comercializadoras*") can sometimes be challenging for energy communities. IP7 notes the role of the suppliers should be limited and that energy communities should not impose on its members to be with a certain marketer. It must be a free and individual decision. On the other hand, there are also marketers that are interested in creating energy communities, or energy cooperatives that are marketers. IP1 mentioned Som Energia, which could be considered an energy community, because the organisation is based on a participatory model, they have a strong social component and they have local groups in each region that are sovereign and can make their own decisions according to their specific context. They also promote and assist other initiatives, e.g. through energy training or the reward of initiatives.

4 Case: Design of local energy communities in the Metropolitan Area of Barcelona

"(…) *we want a city where self-generation and self-consumption are the norm, with a fair, democratic and renewable energy model that will enable us to be renewable and carbon neutral by 2050*."
(Ajuntament de Barcelona, Climate Emergency Declaration)

4.1 Description of new energy communities currently developing in Barcelona

In the following chapters, the information on relevant context factors and characteristics to be considered in the design of local energy communities retrieved in the previous chapters is applied to the case of the AMB. Two energy community projects currently developing are described. After an analysis of relevant contextual factors in the AMB, different technical and organizational recommendations are made that refer both to the general creation of energy communities in the AMB, but also make reference to the two cases.

4.1.1 Comunitat Energètica del Poblenou

Since 2021, work has been underway in Poblenou, a district in the east of Barcelona, to create an energy community, where citizens can actively participate and benefit from shared renewable energy generation (Energia Barcelona, 2022; IP5). The project has been initiated by the neighbours' association of Poblenou and implemented together with the Barcelona City Council, the public energy agency Energia Barcelona and the school "*Instituto Quatre Cantons*" including its family association. The legal form has not yet been decided upon, but probably it will be an association.

Figure 4-1: Installation of the Comunitat Energètica del Poblenou (source: Energia Barcelona, 2022)

A first PV installation (108 modules) with a potential of 58 kWp has been installed on the roof of the school (**figure 4-1**). The administrative procedure necessary for the grid connection is still in the process of authorization. The annual generation of 73'750 kWh will be partly consumed by the school itself, but also by other municipal buildings nearby (e.g. another school, a civic centre and a fire station) and local residents living within a 500 m radius. The fixed distribution coefficients assign about 500 W to each household.

Figure 4-2 illustrates the main actors and structure of the project. The objective is to gradually expand the community and add generation as well as additional members. For example, it is planned to also install panels on the roof of the school "*Instituto María Espinalt*", which already has a PV façade and is located at 250 m distance. The whole zone was identified as suitable due to an elevated number of municipal buildings and due to the great interest by citizens.

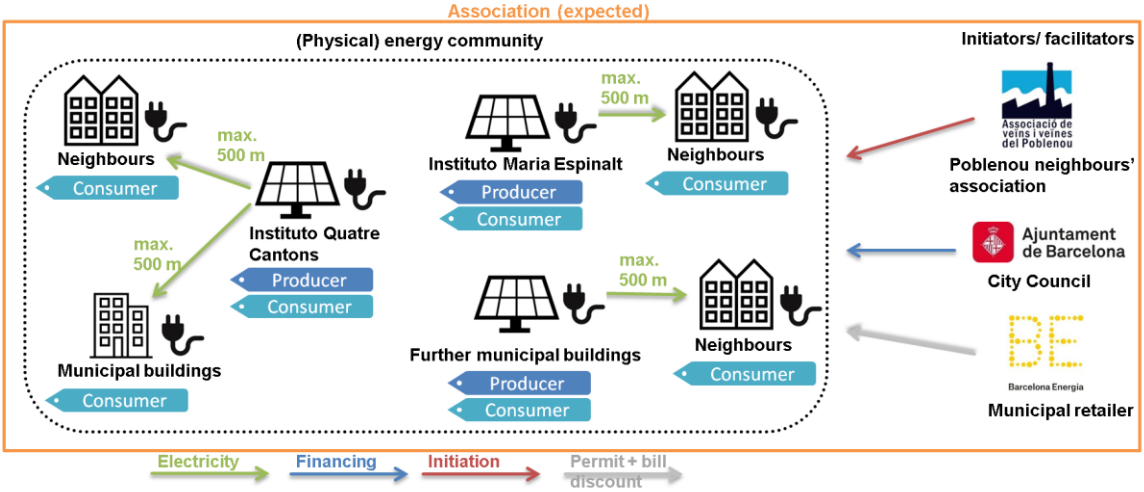

Figure 4-2: Actors and structure of the project "Comunitat Energètica del Poblenou" (own elaboration)

A meeting was held in spring 2022 with interested neighbours and about 30 families signed up. For the moment, participants must have Barcelona Energia as their distributor as it is a pilot project under financing of the municipality and there is also no participation fee. After the pilot phase, the project shall transition into a normally functioning energy community and the conditions will be reviewed.

4.1.2 Som Comunitat Energètica del Barcelonès SCCL

The energy community "*Som Comunitat Energètica del Barcelonès SCCL*" is still at an earlier phase in its development and currently in the process of identifying a suitable roof for a first installation (status of April 2022). In contrast to the energy community in Poblenou, there is no direct involvement of the municipality at the moment. The core group consists of volunteers of the local group of Barcelona of the cooperative Som Energia. The objective is to create local energy communities in the Barcelonès region. It is seen as a complementary project to Som Energia that allows participating in collective PV self-production without, for example, having the panels on an own terrace (Som Energia, 2022). The actors and the structure of the project are presented in **figure 4-3**.

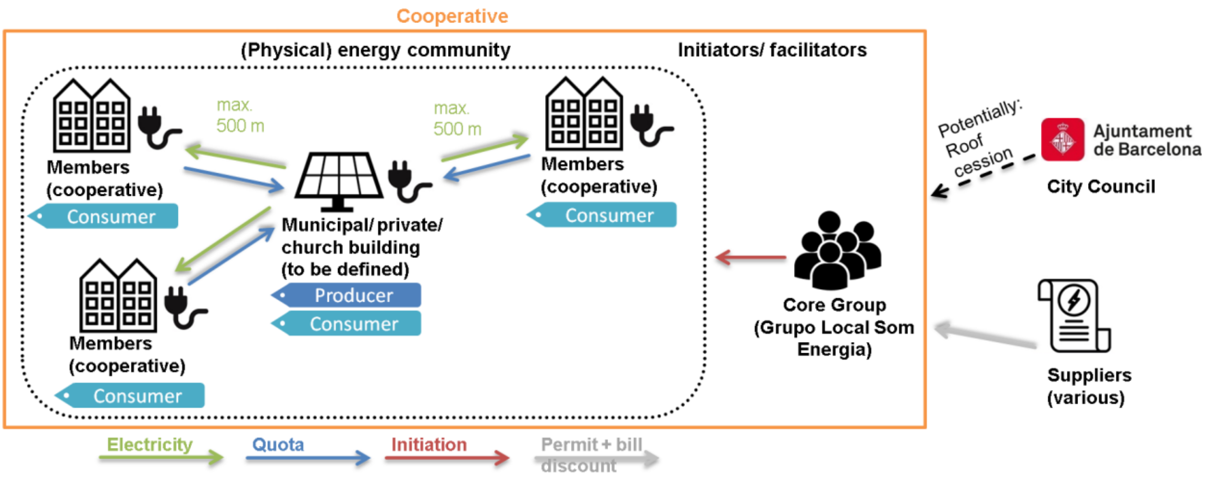

Figure 4-3: Actors and structure of the project "Som Comunitat Energètica del Barcelonès SCCL" (own elaboration)

To initiate the project, the volunteers have given talks and conducted a survey among members of Som Energia in the area of Barcelona. More than 160 persons responded to the questionnaire, which is sufficient to initiate the project. On January 31st, the act of constitution of the cooperative was signed (SCCL stands for Sociedad Cooperativa Catalana Limitada).

Similar to the case of the energy community of Poblenou, the vision is to create several installations in different areas of the city. An installation could be either owned by the cooperative or, if there is a group of people already constituted as an association or cooperative, to adopt a shared ownership. Currently, the group searches for a suitable roof of private or public ownership (e.g. municipal sports centres, church buildings, schools, governmental buildings, markets), on which solar panels are placed and the members of "*Som Comunitat Energètica del Barcelonès SCCL*", who live within 500 m of the installation, can benefit from a share of the electricity generated, just as if they had PV panels on their own roof.

Criteria for the identification of a suitable roof include that the surface area should be sufficient to be able to install between 50 and 100 kWp, as a very low quantity leads to higher costs than purchasing a larger quantity of panels. Moreover, the orientation, shading and accessibility are considered. The group works with an engineering company who also assesses the technical and economic viability. Also, the conditions for using the roof, for example in case of a municipal building, are considered. In any case, the respective building would form part of the energy community, as a PV installation by law must be linked to a meter in the building where it is located.

4.2 Contextual analysis

The contextual analysis is structured according to the four critical categories of context factors previously described (chapter 2.5). The focus is placed on the aspects that are considered particularly relevant and characteristic for the Metropolitan Area of Barcelona.

4.2.1 Physical factors

Renewable energy resources/ climatic conditions. The map of the specific PV power output [kWh/kWp] in Europe (**figure 4-4**) illustrates that the prerequisites for solar energy in Barcelona are favorable. The global horizontal irradiation in Barcelona is on average 1’720 kWh/m^2 per year, with 2’799 hours of sunshine in 2020 (Ajuntament de Barcelona, 2021b). With regard to the average monthly PV power output, the highest amount can be generated between March and September.

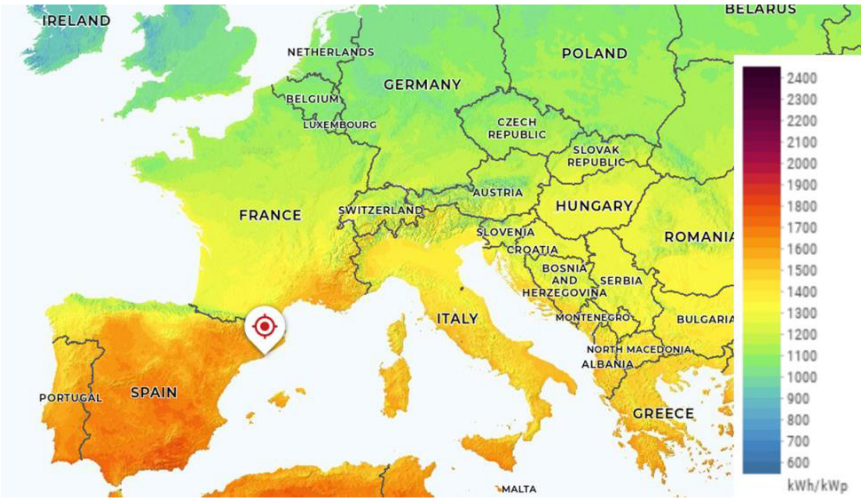

Figure 4-4: Specific photovoltaic power output (kWh/kWp) in Europe (World Bank Group, 2021)

The City Council has created the Barcelona Energy Resources Map, which shows the potential generation for solar thermal, solar PV and mini-wind power on Barcelona’s buildings (Ajuntament de Barcelona, 2022a). The generation potential for roof terraces is estimated to be 1’191 GWh/year for solar PV energy, which corresponds to about 60 % of the electricity consumption of the domestic sector.

Wind is above all available in the higher areas of the city and the conditions are assessed as generally favourable. There are 6000 to 7000 hours with availability of wind resources with a speed between 5 and 40 km/h. The potential generation is estimated to be 500 kWh per year. The use of biomass in Barcelona is not widespread. Reasons include the high cost of space or the general absence of a culture of use of biomass in cities, as this is more typical in rural areas (Ajuntament de Barcelona, 2011). All in all, solar energy seems the most viable option for energy communities in Barcelona.

Topography and geographic (urban) potential. Barcelona is a very compact city, characterized by a high residential density and an old housing stock. The density leads to a pronounced heat island effect, leading to great temperature differences between the urban districts and less urbanized zones of the Metropolitan Area. In the context of rooftop PV, shading from adjacent buildings can therefore be an issue (Ajuntament de Barcelona, 2021b). On the other hand, the blocks – especially in the urban fabric of the Eixample district – have a quite regular skyline ensuring total exposure of the roofs and therefore a bigger surface that is potentially exploitable (Curreli and Roura, 2010). About 67 % of the buildings have flat roofs that are generally accessible and 20 % of the roofs are estimated to have even optimal characteristics for solar energy generation (Ajuntament de Barcelona, 2022b). Due to the old housing stock, it should be checked if buildings are protected. Moreover, as mentioned in the interviews, many roofs are divided into small terraces for individual use.

4.2.2 Technology factors

Energy needs and demand profile. Due to Barcelona's density, every kWh used can be distributed among more people, leading to a moderate energy consumption compared to many other cities. According to figures from 2019, the domestic sector is among the biggest consumers of energy in Barcelona and accounts for 20.7 % of the GHG emissions. It can be assumed that this share has increased during the COVID-19 pandemic, with more time spent at home and more people working remotely. The transport sector is still over-dependent on motor-vehicles and accounts for the highest share of GHG emissions, which indicates that energy communities can also make an important contribution with activities related to electric mobility. The Climate Energy Declaration states that new consumption patterns linked to e-mobility are anticipated, which leads to a bigger need for power distribution infrastructure (Ajuntament de Barcelona, 2021b). The share of electric vehicles in the fleet in the AMB (**table 4.1**) has grown from 0.8 % in 2015 to 4 % in 2020.

Table 4-1: Type of propulsion (%) of the circulating vehicle fleet in the AMB (Àrea Metropolitana de Barcelona, 2022b)

2015				**2020**			
Gas	Diesel	Electric/ hybrid/ others	Total	Gas	Diesel	Electric/ hybrid/ others	Total
33,8	65,4	0,8	100,0	42,9	53,1	4,0	100,0

Energy mix. Most of the energy consumed in Barcelona (according to the Catalan energy mix) is based on fossil (69.2 %) or nuclear sources (23.4 %) with 7.5 % being from renewable sources, as can be seen in **figure 4-5**. This indicates a high energy dependency, which is considered as an enabler for energy communities (s. chapter 2.5).

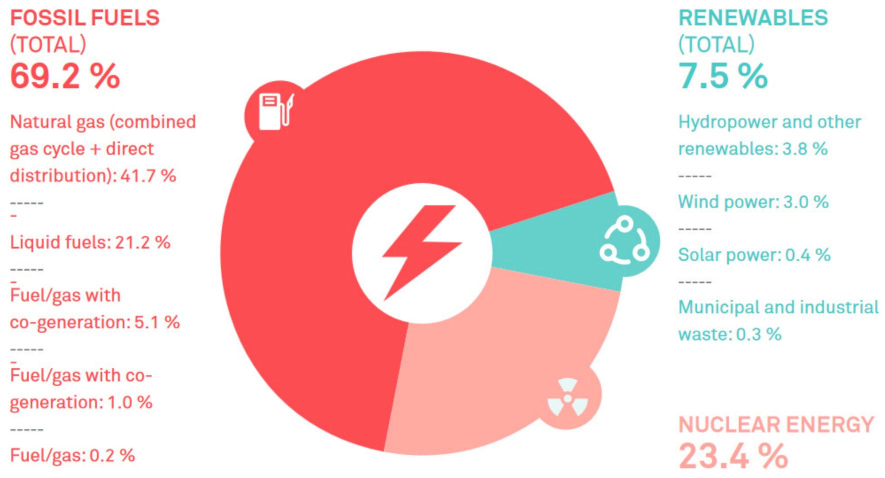

Figure 4-5: Final energy sources according to the Catalan mix (Ajuntament de Barcelona, 2021b)

Existing energy infrastructure. Within respect infrastructure for the electricity generation in the Metropolitan Area of Barcelona, in the ordinary-regime (OR), corresponding to nuclear, coal, fuel oil, gas and large hydro power plants, there are two large combined cycle power plants (CCPP), the Plant of the port of Barcelona and the Plant of Besòs. In the special regime (SR), corresponding to renewables, waste and cogeneration, the main production facilities are ecoparks, the energy recovery centre in Sant Adrià de Besòs, the Vall d'en Joan landfill and the energy generation plant of the Zona Franca. Regarding the electricity network, there is one 400 kV substation within the metropolitan area, with a 220 kV network delivering energy from these nodes to the main consumption points, from where it is distributed through a medium voltage grid of mostly 25 kV (AMB, 2021).

According to Ajuntament de Barcelona (2021c), Barcelona's municipal PV installations on pergolas, municipal buildings and public spaces have an installed power of 3'525 kWp with a yearly generation of 4'358 MWh.

Roll-out of smart-meters. The roll-out of smart-meters is well-advanced in Spain and almost accounts for 100% of the electricity meters. In the province of Barcelona, the share was 97.44 % as of 2019 (Smartgridsinfo, 2019).

4.2.3 Institutional factors

Political agenda and policies promoting energy communities. As mentioned beforehand (chapter 1.1), renewable energy targets and also specifically the promotion of local energy communities are embodied in several plans, agreements and roadmaps, such as the Framework Program for Energy and Climate Action 2020-2023 of the AMB, which includes the measure "Support and dynamism to create energy communities" with the objective that until 2030, 300 local energy communities shall be created in the metropolitan area (AMB, 2020).

Regulatory framework. Although the regulatory conditions for self-consumption and energy communities in Spain have improved over the last years (for example, with the repealing of the sun-tax, s. chapter 1.3), there are still aspects being criticized, as mentioned in the interviews, such as the 500 m limit or that energy communities should be granted competitive advantages compared to traditional players of the energy market.

Commitment of the local administration. Local public authorities and city administrations play a key role in the promotion of local energy communities, as confirmed also by statements of interview partners. Initiatives such as the mentioned Association of Municipalities and Entities for Public Energy (*"Asociación de Municipios y Entidades para la Energía Pública"*, AMEP) in Catalonia with involvement of 74 municipalities hints at a general commitment of many local administrations. According to some interviews, the city of Barcelona lags slightly behind in comparison with other cities and towns in Catalonia. On the other side, cases such as El Prat de Llobregat or the Poblenou energy community show that the basis is laid for projects with involvement of the local administrations and, possibly, further projects can be expected in the future which will be supported by the city council. Energy communities are also addressed in bodies such as the Council for Climate Emergency and Ecological Transition.

Administrative and bureaucratic conditions. It was noted in the interviews that although some processes have been streamlined in Barcelona and improvements have been made, there are still bureaucratic and administrative hurdles with respect to the creation of energy communities, partly due to the size of the municipality. It was also mentioned that the accessibility of suitable roofs for solar PV could be improved by the local authorities, for example by communicating about available roofs.

Structure of the energy market. As it is usually the case in Spain, the grid is not owned by the municipality, but by electricity companies. However, the Barcelona City Council and the Barcelona Energy Agency (a public consortium consisting of a number of authorities such as the Barcelona Metropolitan Area, the Catalan Energy Institute as well as universities) created in 2018 the municipal retailer Barcelona Energia. It purchases energy from producers and distributes it to citizens, with the objective to contribute to the city's energy transition. By involving citizens in decision-making, making available renewable energy at affordable prices and taking measures against energy poverty, more independence shall be created from the profit-oriented oligopolistic model.

4.2.4 Community factors

Classification (rural/urban). The generally urban context of the AMB, especially in the city centre itself, creates a higher complexity of the network of involved actors. It should also be assumed that the population is highly heterogeneous. In order for energy community projects to be inclusive, care should therefore be taken to integrate different sections of the population.

Awareness, attitude and skills of the base community. The general awareness of the population of the AMB with respect to climate change and energy transition can be evaluated as quite high. A survey conducted by the city council in 2019 revealed that 89 % of Barcelona's residents were worried about climate change (Ajuntament de Barcelona, 2019). Various initiatives indicate a fairly high level of active participation by the population on issues such as the energy transition, for example public consultations on the topic through the platform for citizen participation "Decidim.Barcelona" or the Citizen Council for Sustainability. However, this certainly does not concern all population groups and, moreover, awareness and knowledge specifically in relation to energy communities are still expandable among the population. Therefore, it would be important that energy communities include awareness-raising among their activities.

Cultural and historic context. A tradition of local energy activism or of acting in groups and association contributes to the development of local energy communities. In the interviews (IP5) it was mentioned that cooperatives have a lot of prestige on a social level in Catalonia, but that there is not a high number of initiatives. Som Energia can be named as an important cooperative in the field of energy communities, as its local groups initiate projects, such as the "*Som Comunitat Energètica del Barcelonès SCCL*". Moreover, the example of the Poblenou energy community illustrates the role of neighbourhood associations in the creation of energy communities. The neighbours' association of Poblenou has a history of about 50 years. After the end of the dictatorship in Spain, many neighborhood movements were born. In Poblenou, the association is very active and the district has been undergoing a transformation during a longer time already (such as the innovation district 22@).

Demographic indicators. Relevant demographic indicators to be taken into account include the already mentioned high population density, or the poverty risk rate, which is closely related to the issue of energy poverty. As described in the introduction chapter, about 170'000 people in Barcelona were affected by energy poverty in 2016. This highlights the importance of initiatives to reduce energy poverty.

Availability of advisory service centres and umbrella organisations. At the moment, no umbrella organisations could be specifically identified for energy communities in Barcelona on a local or regional level, apart from the Som Energia cooperative. As the number of projects increases, an exchange in such a framework would certainly be profitable. On the European level, there is the European federation of renewable energy cooperatives. In the AMB, there are different advisory centres on related topics, such as Barcelona's Energy Advisory Points (PAEs). Within the PRTR, a network of Community Transformation Offices to advise energy community projects will be established.

Existence of "core communities". As described before, experimental model actions that generate core communities can contribute to the removal of barriers. In the case of the Poblenou Energy Community, for example, it is possible to speak of such a core community, as it is a pilot project that is intended to expand and initiate further projects.

4.3 Recommendations on the organizational design

4.3.1 Legal form

The *Som Comunitat Energètica* community has chosen the form of a cooperative. As previously described, this is considered a suitable form for energy communities, as cooperatives are organized in a democratic and open way, and the primary objective is not to generate financial profits. Next to cooperatives, associations are among the most frequent legal forms of energy communities in Spain, which might be the form that will be chosen be the Poblenou community. In case of associations, also juridical persons (not only natural persons) can be members, which might make the participation of the city council or Barcelona Energia easier. Should a project consider the formation of a limited partnership, it is recommended to assure that the consumer-shareholders have appropriate control rights and participation. In any case, it is recommended to any new energy community project in the AMB to establish a legal entity in order to comply with the legislation on energy communities and to start evaluating the most suitable legal form early on.

4.3.2 Actors and structure

In **figure 4-2** and **figure 4-3**, the structure of the two local energy communities "Comunitat Energètica del Poblenou" and "Som Comunitat Energètica del Barcelonès" was presented. The figures illustrate the involved actors, their roles as e.g. consumers or producers as well as their interrelation in terms of flows of electricity, financing etc. The structure includes both the physical energy community (i.e. the building(s), where the PV plants are located, and the neighbours that receive electricity) and the initiator group. As described in the literature review, an actor can take on several roles, e.g. both producer and consumer. Likewise, a volunteer of one of the initiating organisations (such as the Poblenou Neighbours' Association or the local group of Som Energia) can also be a consuming neighbour, for example.

Both energy communities have the prerequisites for a gradual expansion. Thus, according to the concept of the energy community in El Prat de Llobregat, further "islands" can be formed, each consisting of an installation and the surrounding consumers. Although each installation can only supply electricity to the members within a radius of 500 m, there are other aspects, such as a mobile app, which can be applied to the entire network construct and thus achieve economies of scale. This was implemented by the energy community in El Prat.

Next to the collaboration among internal actors, it is recommended to seek outward cooperation, e.g. with other energy communities for the exchange of experiences and best practice approaches.

4.3.3 Engagement and governance

Various aspects to be taken into account with respect to engagement and governance have already been described in more detail in chapter 2.6. For the specific case of energy communities in the AMB, the following recommendations are highlighted:

- For the start-up and engagement process, it is recommended to set up a multidisciplinary core team and to follow established methodologies, such as Living Labs. More and more projects financed with European funds are using Open Innovation or Living Lab methodologies with the aim of a more participatory innovation. In Barcelona, universities are offering assistance in Living Lab processes.
- Care should be taken to not only reach out to people within a "bubble" of energy citizens and taking into account the heterogeneity of the population of Barcelona. People beyond those with an already high awareness and with prior knowledge should be able to get involved, at least in the longer term. In case of the Som Comunitat community, this might refer to people outside of the local Som Energia group. Likewise, the Poblenou energy community can increasingly reach out to citizens outside of the environment of the schools or the involved associations, although this has also been initiated with the meeting with interested neighbours. However, proactively approaching people affected by energy poverty could be another step, for example.
- It is important to guarantee that the effective control of the energy community is in the hands of the citizens, and no single shareholder owns more than 33% according to the

RED II. On the decision-making spectrum, the "one vote per actor" model could be chosen if feasible.

- As the issue of energy poverty has received attention in Barcelona, affected families should be empowered. A possibility is a solidarity scheme, where a share of the energy goes to families affected by energy poverty (s. "*Barrio Solar*" project in Zaragoza).
- A hybridization between bottom-up and top-down models is recommended, including collaboration with the municipality. In one of the questionnaires it was mentioned that expert advice should be sought where necessary. The network of Community Transformation Offices to be established could make support from public authorities more accessible.
- According to the legislative framework, energy communities must be based on open participation. In case of the Poblenou energy community, it is therefore recommended to review the conditions after the pilot phase, e.g. with respect to the required supplier.

4.3.4 Activities

Chapter 2.6.2, as well as the analysis of the background study, describe various activities that energy communities can consider. The following recommendations are pointed out for energy communities in the AMB:

- Start with activities directly related to energy generation, and, as the community consolidates and grows, diversify (becoming more comprehensive by adopting an integrative vision and addressing more lines of action), both within the electricity sector (e.g. electric mobility) and beyond (e.g. educational programmes, environmental conservation actions) (s. "*Alumbra*" energy community for different lines of action).
- Electric mobility activities (e.g. recharging points) have a great potential in Barcelona (as mentioned, the transport sector is still over-dependent on motor-vehicles, but the number of EVs is growing).
- Activities against energy poverty, e.g. a solidarity scheme or information campaigns.
- "Learning community": Information and awareness raising activities, for example with respect to reading and interpreting electricity bills, responsible contracting or consumption. In case of the Poblenou energy community, the project also serves as an educational platform to teach the children of the involved schools about the need to move towards a clean energy model.
- Digitalization: Implementation of an app to learn how to save on bills or adjust consumption (s. energy community of El Prat de Llobregat).

- Consulting activities, e.g. for the implementation of energy communities (as it can be expected that more initiatives will surge in Barcelona during the coming years) or energy efficiency.
- Participate in urban regeneration activities, such as the planting of trees or vertical forests on the balconies or facades of buildings.

4.4 Recommendations on a technical design and determination of the solar PV potential for an example roof

In this chapter, general recommendations are made for a technical design, considering the setting of the AMB. As described, the Poblenou energy community already has its first PV installation in place and further installations are planned. The Som Comunitat project is currently still in the process of identifying a suitable roof (as of April 2022). The energy generation assets described below therefore represent a theoretical and approximate design with an exemplary character for either an extension of the Poblenou community, a roof for a first installation for Som Comunitat or a roof for a completely new energy community in Barcelona. In reality, a more detailed investigation and data collection on the example roof would have to be carried out.

4.4.1 Creation of an overview of suitable roofs (geographic potential) and identification of an example roof

As described in the methodology, in the first step an overview shall be created in QGIS on suitable buildings for the installation of rooftop PV in the AMB. For reasons of data availability, this visualization is restricted to municipal buildings. The resulting map (**figure 4-6**) is a merger of two sets of information: (1) buildings owned by the municipality (shapefiles) and (2) municipal facilities with existing rooftop PV installations (point data). The created map allows two main conclusions: First, it shows that a significant potential has already been installed on many public buildings and that there is an effort on the part of the public authorities. The installed potential on municipal rooftops displayed in the map amounts to 2’355 kWp. This excludes the installations on pergolas or public spaces mentioned in chapter 4.2.2. However, as a second conclusion, the map also shows that a significant potential of PV generation on rooftops still remains untouched. And this does not even include private roofs.

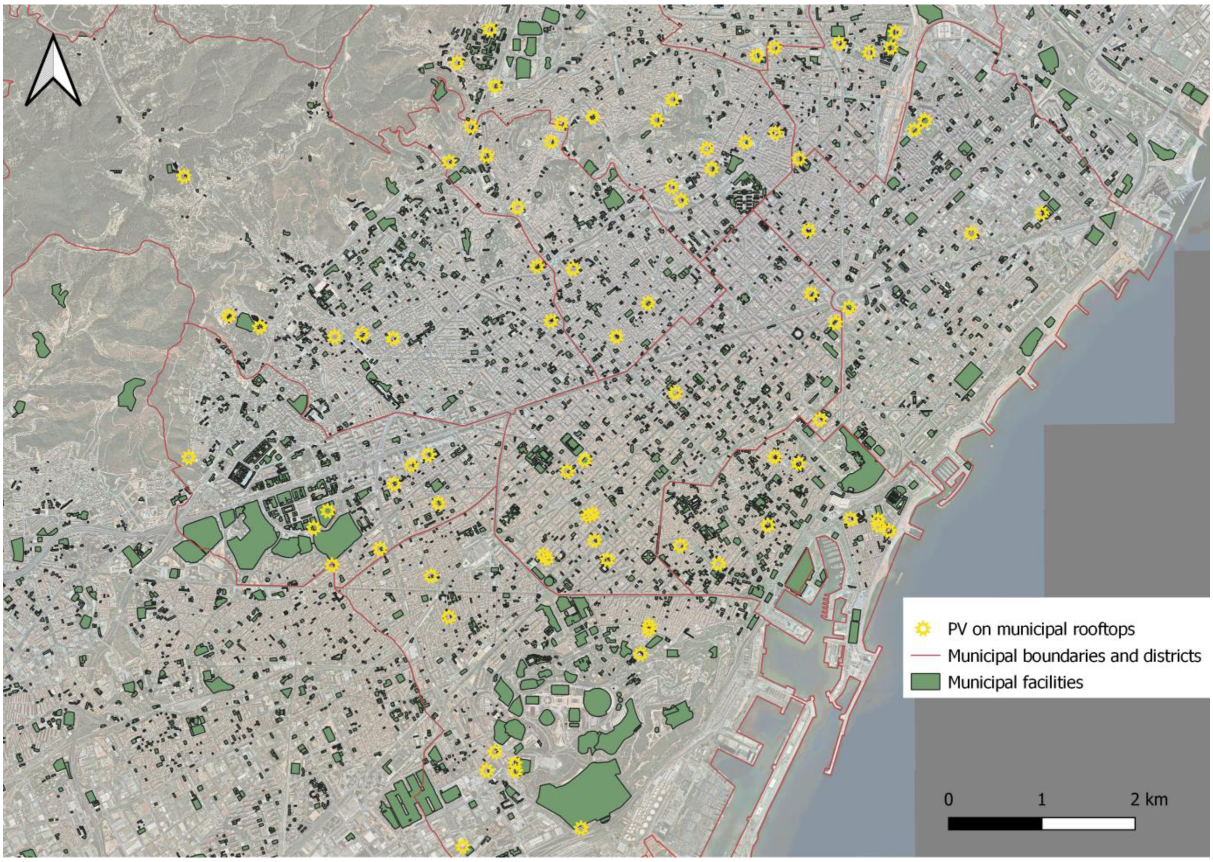

Figure 4-6: Overview of municipal buildings in Barcelona including existing rooftop PV installations (own elaboration based on information from: Ajuntament de Barcelona, 2021c; Área Metropolitana de Barcelona, 2022a; Institut Cartogràfic i Geològic de Catalunya, 2022; Open Data BCN, 2015)

Based on the created map, it is possible to identify suitable roofs, for example visually by applying criteria of the geographic potential (such as: roof inclination, superstructures on the roof, or closeness and comparative height of other buildings and the resulting shading). Identifying suitable roofs for an energy community would be easier if information were available about which public roofs are accessible or if there were some kind of platform where private owners could also offer roofs for a community installation.

The identification is even more complicated in case of private roofs, as data on existing installations etc. is not as readily available as for public buildings. It was therefore decided to focus the example design on a private roof in order to raise awareness to the fact that for a true energy transition, involvement of all sectors is needed and that there is significant potential also on other buildings than public ones.

The chosen example roof is located in the neighborhood El Clot in the Sant Martí district of Barcelona. The property has several buildings, which house, for example, a foundation and a carpenter's workshop. In addition, right next to it is the Urban Garden of El Clot. For the design, one of the buildings was chosen on whose roof no shadow of the adjacent buildings falls.

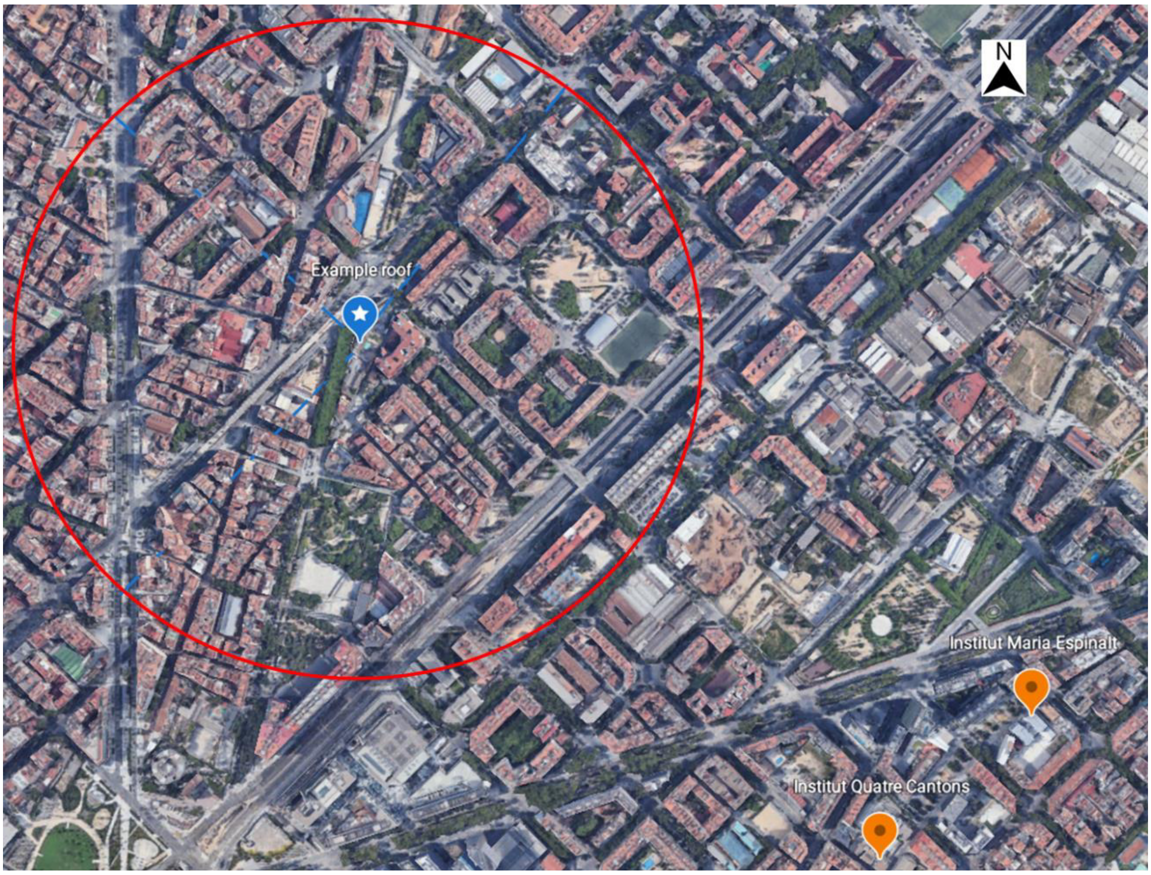

Figure 4-7: Location of the roof for an example design including a 500 m radius (own elaboration with Google Earth, 2022)

Figure 4-7 shows a map of the location of the example roof and the 500 m radius. The building is at about 1 km distance from the school "*Institut Quatre Cantons*", visible below right, where the first installation of the Poblenou Energy Community is located. This underlines that the example roof could, in the case of the Poblenou Energy Community, be used to include also private buildings for installations as part of an expansion in the future. In case of the Som Comunitat energy community, it could be considered as one of the first roofs; or it could also be used to create a completely new energy community. There are many residential buildings in the immediate vicinity, so the energy community could consist of the building itself as well as neighbours from the surrounding area.

4.4.2 Physical energy assets and example design

4.4.2.1 Energy generation assets

An approximate design of the PV installation was created in order to estimate the annual production. The roof inclination was estimated at 22° based on a measurement with Google

Earth and the orientation of the roof is southeast, i.e. with an azimuth of -45°. The main input parameters for creating the design with the K2Base tool are listed in **table 4-2**.

Table 4-2: Main inputs for the design with K2Base

Loads	Roof					Module array		
Topography/ terrain category	**Roof type**	**Roof shape**	**Building height**	**Roof pitch**	**Roof orientation**	**Layout**	**Installation type**	**Module orientation**
Protected/ category IV	Gable roof	Rectangle	12 m	22°	South-East	Complete roof	Parallel	Landscape
			Estimated with GoogleEarth					

Figure 4-8 shows the resulting design with a quantity of 55 modules of 400 W and a total installed capacity of 22 kWp. For a more accurate design, more precise data would have to be collected, for example on the geometry of the building, the roof structure or the shading with the help of a simulation.

Figure 4-8: PV installation designed with K2Base

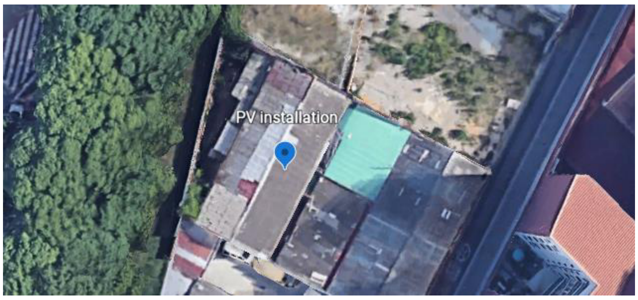

Figure 4-9: Selected private roof for an example design

Subject to a more detailed examination of the roof structure, the number of modules in the design might be overestimated. On the other hand, there might be the possibility to install further modules on other buildings on the property. Therefore, the approximate design is deemed adequate to estimate a potential annual generation.

4.4.2.2 Potential electricity generation (technical potential)

Based on the design, the monthly and yearly PV energy output was determined using PVGIS (s. PVGIS report in **Annex C**). The estimated yearly energy output of 31'390 kWh can be distributed among the members of the community according to determined coefficients, e.g. 40% of the generated electricity is destined to the building itself and 60% to the participating households. In case of 20 participating households this would imply the assignation of about 942 kWh to each household. As a reference, an average household in Spain consumes about 2'992 kWh per year (Red Eléctrica de España, 2010). The coefficients could also be based on proportional consumption or on a corresponding contribution rate.

When comparing the monthly energy output (**figure 4-10**) with the monthly consumption of a standard household (**figure 4-11**), it is evident that while production is higher in summer due to increased solar radiation, the consumption is higher in winter due to aspects such as a higher use of heating and lighting. There is also a peak in July due to air conditioning. Especially in April, June, August and September, a higher proportion of the actual demand could therefore be covered with PV energy from the installation.

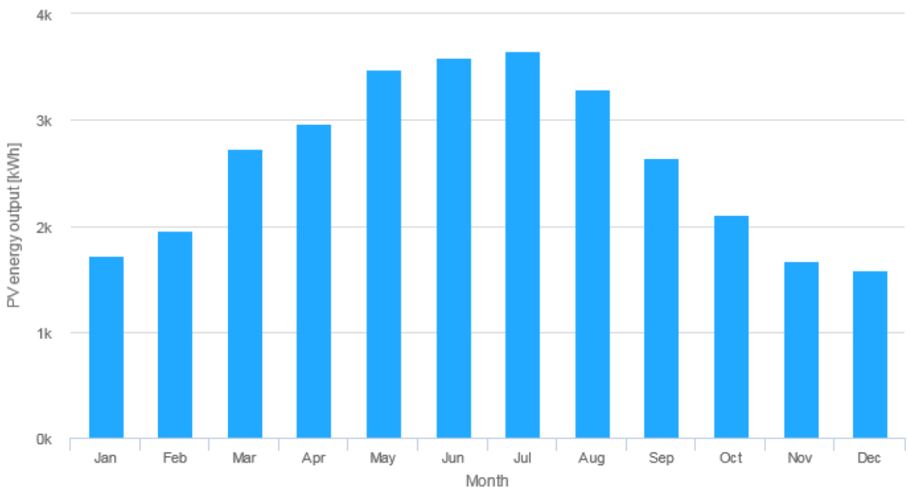

Figure 4-10: Monthly energy output from the PV installation estimated with PVGIS

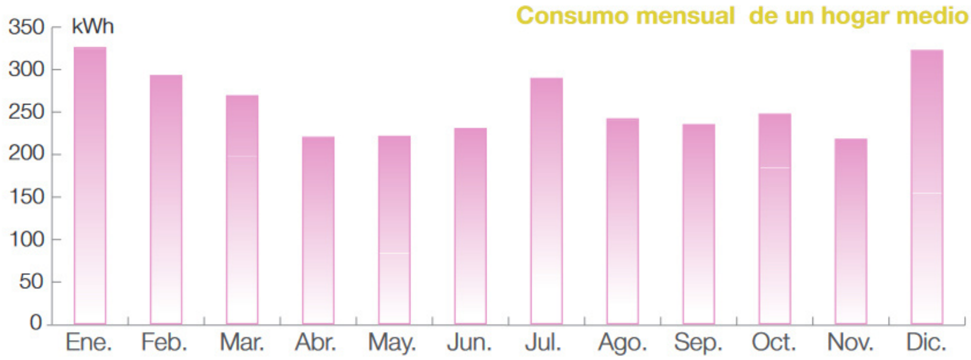

Figure 4-11: Monthly energy consumption of a standard household (source: Red Eléctrica de España, 2010)

The comparison is conducted only on a qualitative basis, as the production data corresponds to the total amount of electricity produced from the installation, while the consumption data corresponds to a standard household, i.e. only one member of the community. However, the relative variation can be compared.

Due to the temporal variation of solar energy, it is also important to consider the relationship between production and consumption throughout the day. **Figure 4-12** and **figure 4-13** represent the hourly PV energy production in winter and summer, respectively. The moments of peak consumption in each case, which are illustrated in **figures 4-14** and **4-15**, are also indicated in the figures representing the production.

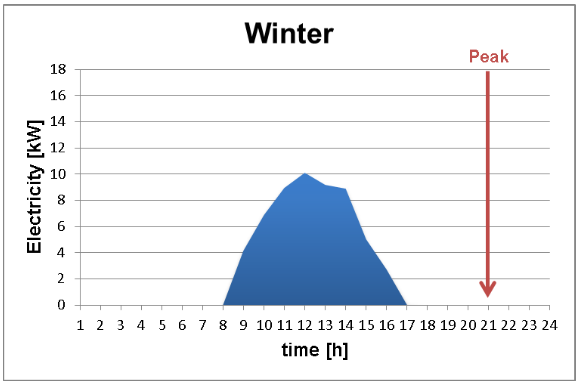

Figure 4-12: Hourly PV energy production in winter (average 2011-2020)

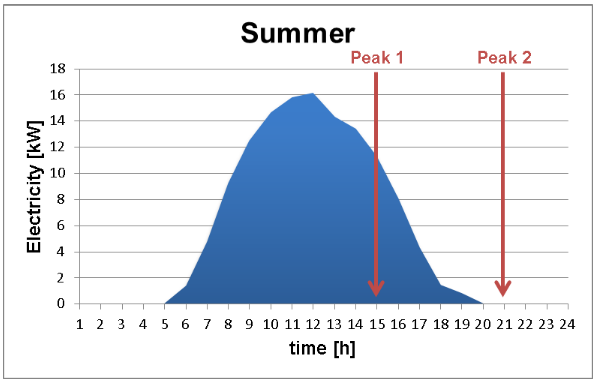

Figure 4-13: Hourly PV energy production in summer (2011-2020)

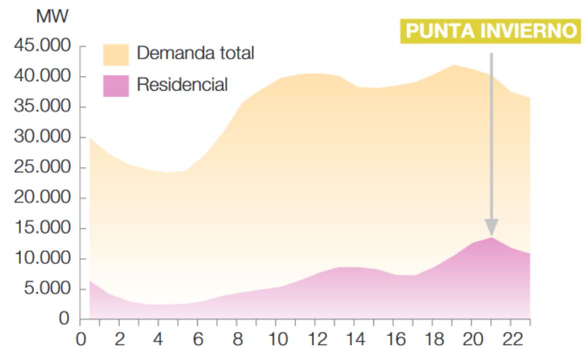

Figure 4-14: Hourly electricity consumption in winter (residential and total) (source: Red Eléctrica de España, 2010)

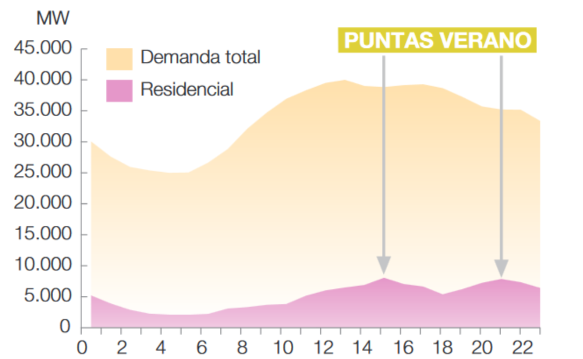

Figure 4-15: Hourly electricity consumption in summer (residential and total) (source: Red Eléctrica de España, 2010)

Around noon, a surplus might be generated, depending on the true electricity consumption of the building itself and the number and consumption of other energy community members. In any case, the generation is at its peak at 12:00, while the consumption has its peak at 21:00 in winter and two peaks at 15:00 and 21:00 in summer.

Although a more precise quantitative analysis, especially of consumption, would have to be carried out, the conclusion can be made that there might be a potential for electricity storage during the day and usage during the peak hours, as illustrated in **figure 4-16**.

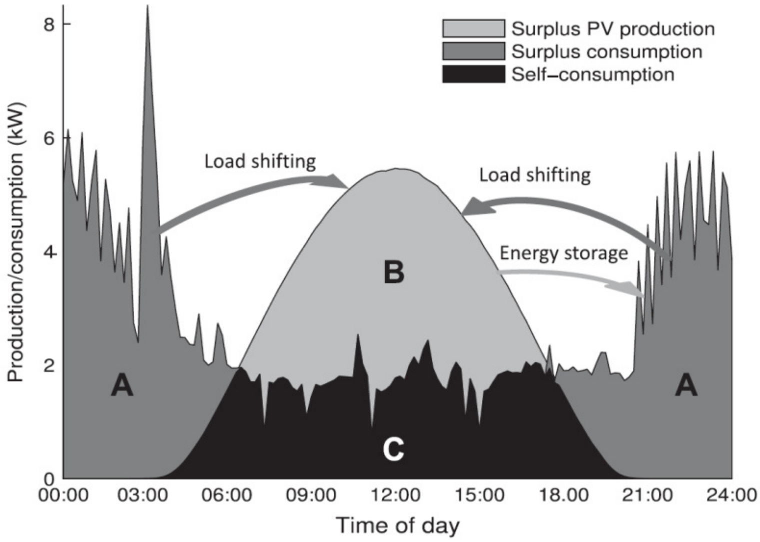

Figure 4-16: Schematic outline of daily net load, net generation and absolute self-consumption (Luthander et al., 2015)

It is important to consider that the consumption of the building itself can be expected to be more uniform during business hours and without a peak in the evening. Moreover, the dynamic between weekday and weekend is also expected to be different among the building with the installation and the households. The building is estimated to have significantly less consumption on the weekend. Thus, dynamic coefficients, which might be implemented in Spain in the near future, would likely contribute to increasing the self-consumption rate, as a higher share of electricity could be assigned to the households forming part of the local energy community on weekends.

4.4.2.3 Storage units and charging stations for e-mobility

The analysis has shown that it is important to consider the variation in load and production. In order to increase flexibility, the inclusion of storage units could be considered as part of the physical energy assets. During hours of overproduction, the electricity may be accumulated in a battery storage system and can then be used at other times of the day. The importance of storage was also mentioned in the questionnaires. A potential layout of a community energy storage system (CES) was already illustrated in **figure 2-5**.

The importance and potential of electric mobility activities in Barcelona has already been mentioned several times. When talking about storage, EVs can also be considered as mobile batteries. Therefore, in an advanced stage of the project, a combination of electricity based transport and the use of batteries for transport could also be an option to increase flexibility and the self-consumption rate. The Handbook for Energy Communities of the "*Energiforum Sydhavn*" (2020) describes two possible outlines:

- **Charging station with ON/OFF-control (figure 4-17):** The electric vehicle can be charged at the charging station, but cannot supply power to the grid. An ON/OFF management system allows controlling when the vehicle can be charged in order to optimise consumption.

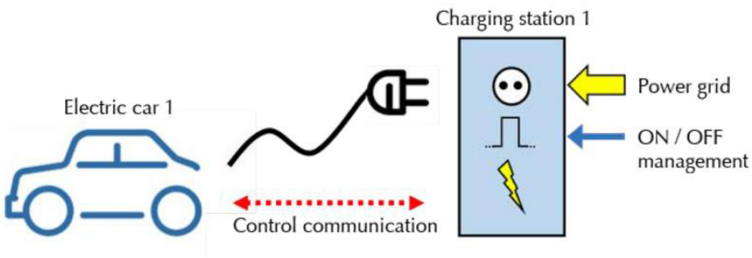

Figure 4-17: EV charging station with ON/OFF-control (source: Energiforum Sydhavn, 2020)

- **Charging station for electric cars with smart control (figure 4-18)**: The vehicle can be charged but also deliver electricity back to the grid (V2G technology). The batteries of the electric vehicle can provide power, for example, during peak load periods, when the price of electricity is higher.

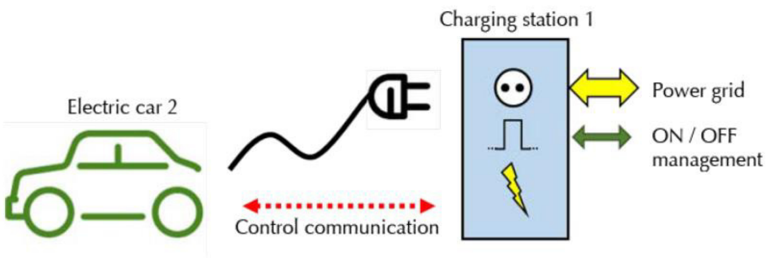

Figure 4-18: EV charging station with V2G technology (source: Energiforum Sydhavn, 2020)

4.4.3 Information and communication technologies (ICT)

Another technology layer for energy communities is the ICT layer. In chapter 2.6.1.2, different ICTs were described. One aspect that is taken up again at this point is the digitalization of energy communities. For example, all members of an energy community could have access to an app, that allows visualizing energy activities or facilitate member participation. The Poblenou Energy Community, in the course of a future expansion, will consist of several generation points forming different (though partly overlapping) “islands” with a 500 m radius. Therefore, similar to the example of the energy community of El Prat de Llobregat, the community could benefit from projects such as a common app that can be implemented on an overarching basis, thus achieving economies of scale.

4.4.4 Connection to the grid

Energy communities can choose an on-grid or off-grid mode, as mentioned. In the given set-up, a configuration with grid-connection is the most feasible. An outline of an energy community with different buildings connected to the grid was provided in **figure 2-7**.

Moreover, Royal Decree 244/2019 covers two modalities of self-consumption with connection to the grid: the connection to the grid could be with or without the consideration of surpluses. As the above analysis has demonstrated, depending on the balance and dynamic of production and consumption, it is possible that surplus energy might be produced and the modality of compensation could be adopted. The simplified compensation scheme is also an option chosen by several projects that participated in the survey for the background study.

With respect to the distribution of the electricity among the community members, the definition of distribution coefficients is also an important aspect. The coefficients could be defined based on the daily electricity consumption, a financial contribution or other criteria. The previous analysis has also shown that the possibility of dynamic coefficients would contribute to the efficient use of energy due to the differing load profiles of households and an office or industrial building.

5 Discussion

5.1 What can be learned from literature and research to date on local energy communities (RQ1)?

First of all, it can be stated that the topic of local energy communities in connection with the availability of scientific literature faces the challenge that it is a very current topic, which is characterised by relatively rapidly changing framework conditions and dynamics. Among other things, the still imprecise legal framework in most countries means that many related concepts often overlap also in research, such as renewable energy communities, citizen energy, self-consumption etc. This also leads to a diverse set of typologies of local energy communities that are highly context-dependent.

The main findings from the literature review can be summarised in the framework represented in **figure 5-1**. A set of physical, technology, institutional and community context factors should be analysed in the initiation phase of the project lifecycle of a local energy community. With the context factors in mind, specific configurations can then be chosen in the design phase (for example, installed energy technology or activities). Moreover, different barriers and enablers have to be considered.

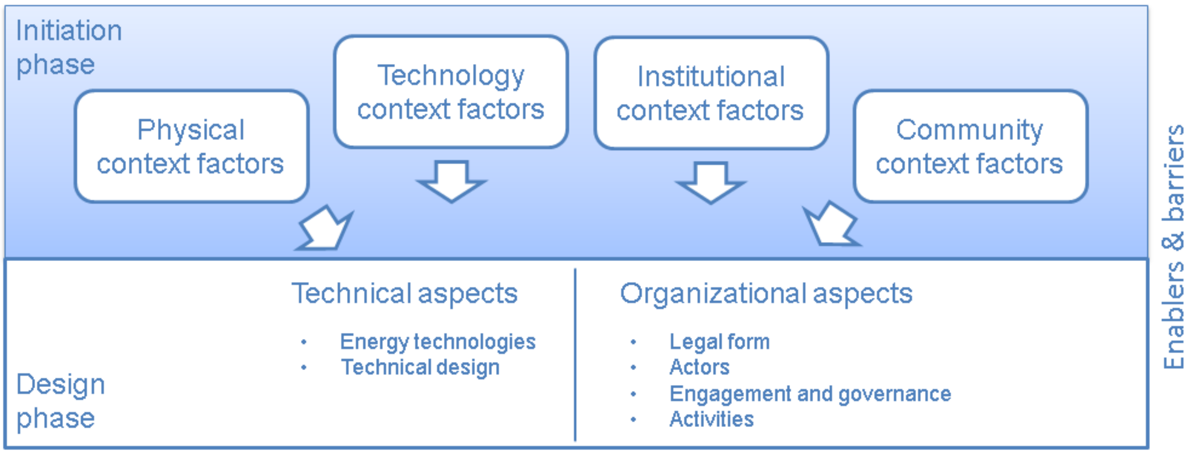

Figure 5-1: Framework of context factors and characteristics relevant for the design of local energy communities (own elaboration)

The relevance of contextual factors also illustrates the importance of local reflections and the consideration of specific conditions. In this sense, this work can make a contribution by analysing the context of the AMB.

Another insight that can be gained from the literature review is the interdisciplinarity of the topic. It is hardly possible in research to approach the topic of local energy communities in a purely technical way, for example, because the regulatory framework has an impact on some technical possibilities.

5.2 What can be learned from practical examples of local energy communities already established (RQ2)?

Compiling and analyzing practical examples makes an important contribution to shedding light on the different typologies of energy communities. Due to the rather imprecise legislation, the profiles of the projects are quite diverse and not all might be energy communities in the strict sense, but they also have many things in common.

In Spain, local energy communities have emerged mainly in recent years, since the publication of the EU Clean Energy Package and the introduction of the concept in this country. Mainly quite young projects or projects that are currently in the initiation phase were identified in the survey among existing projects. Thus, another important contribution of the analysis of existing projects is to enable the exchange on barriers as well as on good practices. After all, many projects face similar challenges.

The majority of the projects considered are located in smaller cities or rural areas. Especially in smaller towns, successful initiatives often seem to emerge in cooperation with the municipal administration. However, as one of the interviewees noted, an energy transition cannot take place without solutions in urban areas. Therefore, there should be a stronger focus on case studies also from urban areas. This highlights again the importance of case studies such as the analysis in chapter 4 of this thesis.

In terms of characteristics, many findings from the literature review could be confirmed, for example with regard to the fact that most projects are based on solar PV. The analysis of the activities carried out or planned by the projects also confirmed that the main focus is on energy production and consumption. This is certainly partly due to the mentioned rather early stage of most projects. However, the analysis also demonstrated that local energy communities can be active in a range of fields of activity, such as in the area of electric mobility, consultancy or educational programmes. It also became clear that many energy community projects specifically plan to carry out measures against energy poverty, such as solidarity schemes.

Important insights were also gained with regard to the framework conditions. For example, the lack of a clear legislative framework was frequently mentioned as a barrier in the expert interviews as well as the drawbacks of existing legislation, such as the limit of 500 m for self-consumption. Another topic mentioned by different interviewees is the accessibility of municipal roofs and the role of the city council in general. The study has shown that local public authorities and city administrations play an essential role, both in the initiation of local energy communities and as collaboration partner.

5.3 How are the conditions for energy communities in the Metropolitan Area of Barcelona and which recommendations can be made (RQ3)?

In Barcelona, the size and complexity of the city administration seems to be an inhibiting factor for the development of some energy communities, and bureaucratic hurdles are also mentioned. Another issue is the identification of suitable roofs for installations. While there is a high potential in Barcelona, a clearer communication of accessible and available roofs might make it easier for initiators to set up new projects.

On the other hand, the projects currently being developed in the AMB, also with the participation of the city administration, show that progress is being made. Furthermore, many contextual factors provide favourable conditions for the development of energy communities, for example the physical potential for renewable energy.

The two case studies considered can make a relevant contribution as pioneer projects in the urban space of Barcelona and provide important insights for the future development of further energy communities. The background is quite different among both cases. While there is a close cooperation with the City Council in case of the "*Comunitat Energètica del Poblenou"*, there is no direct involvement in case of the "*Som Comunitat Energètica del Barcelonès*" project. In both projects, however, the initiation initially came from the citizens. The two examples also demonstrate the importance of citizen groups, such as neighbourhood associations.

The design recommendations have shown that the concept of the local energy community can be implemented well in Barcelona and that, especially in the advanced stage of the projects, activities such as the integration of electric mobility can make a contribution to a more efficient energy use and more sustainable mobility. The analysis of an example design also showed that in energy communities consisting of different types of users, such as public buildings and households, synergies can arise from the differing consumption profiles.

6 Conclusions

6.1 Synthesis

In the introduction, the question was presented: "How can we meet our increasing energy needs and at the same time comply with sustainability goals?” It is obvious that against the background of climate change, the expansion of renewable energies is of utmost importance. In order to achieve this, however, the energy system architecture must be redesigned. Local energy communities enable citizen participation, which is seen as a contributor to a just and inclusive energy transition and has the potential to reduce energy poverty. It is also important to note that local energy communities go beyond mere collective self-consumption and can implement a variety of activities apart from energy generation.

Based on the literature review, a framework was developed which comprises important context factors to be considered in the design as well as possible configurations of energy communities (typologies). Moreover, important barriers and enablers were identified.

The survey among existing projects and the interviews with experts provided further information on the identified relevant contextual factors as well as on the characteristics and typologies of different energy communities in Spain. For example, the conclusion from the literature review that most projects are based on PV energy could be confirmed by the reviewed cases. It could also be confirmed that the activities of energy communities can go beyond energy production and consumption, even though they often focus on these areas, especially in the initial phase. Moreover, insights were gained regarding the handling of surplus energy. Here, many projects choose the path of compensation, but the relevance of storage was also pointed out. In addition, information on barriers and success factors was collected. Similar challenges are faced by many projects and an increased exchange of experiences would be beneficial. It is also important to highlight that the majority of the reviewed projects is located in smaller cities or a rural environment.

Through the analysis of the framework conditions and the two case studies in the Metropolitan Area of Barcelona, it became clear that although certain barriers still exist, such as bureaucratic hurdles, there is generally a great potential for the development of local energy communities due to aspects such as favourable conditions for solar energy or a generally high awareness of the population with respect to climate change or energy transition. The numerous neighbourhood associations also play an important role. Here, a community structure already exists from which projects can develop, such as in the case of the Poblenou Energy Community. In the case of the project "*Som Comunitat Energètica del Barcelonès*", there is also such an existing structure through the local group of Som Energia. A transparent provision of information regarding available roofs for the installation of PV systems would enable projects without direct involvement of the municipality to establish an energy community more easily.

Based on the analysis of the context of the Metropolitan Area of Barcelona, different technical and organisational recommendations have been developed. Regarding the fields of activity, the range can be expanded, for example after a consolidation phase, from activities related to energy production and consumption to other activities, such as related to electric mobility. This is a feasible option considering an increasing share of electric vehicles in Barcelona and the associated need for the expansion of the charging infrastructure.

The design of a PV installation on an example roof could also illustrate that synergies can be created by including different consumer profiles in the energy community, such as office buildings or schools and households. This is especially the case if the government further pursues the possibility of dynamic coefficients of energy distribution among community members.

The thesis at hand was able to contribute to further research on the influencing factors and typologies of local energy communities as well as on the current situation in Spain. In addition, the specific analysis of the context of the Metropolitan Area of Barcelona could illustrate the existing potential as well as provide learnings for the further development of future energy community projects in the urban space.

6.2 Outlook

It can be assumed that more local energy communities will emerge and existing projects will consolidate in the coming years. It remains to be seen to what extent the regulatory framework will develop and further opportunities for energy communities will arise, for example through dynamic coefficients of energy distribution among members or an extension of the 500 m radius for self-consumption. In the latter case, more energy communities could be established with consideration of industrial areas, where distances to residential areas often exceed the limit of 500 m.

By examining further case studies in urban areas, research could help to ensure that energy communities have further reference examples and are promoted, especially considering that in the urban environment, few people have the opportunity to generate renewable energy on their own roof and energy poverty is often an issue.

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Annex A: Questionnaire

Note: The questionnaire was sent to the participants in Spanish

Questionnaire: Local energy communities

Name of the energy community project: Click to enter text.
Place: Click to enter text.
Number of members: Click to enter text.

Part I: Characteristics of the energy community

a) What is the **organizational form** of your energy community?
☐Cooperative
☐Limited partnership
☐Foundation
☐Association
☐Other (please specify): Click to enter text.
Add details (optional): Click to enter text.

b) Please name the most important **stakeholders/ actors**:
Click to enter text.

c) Can community members actively participate in **decision-making**?
☐yes ☐no

d) In which **activities** is your energy community engaged? *(multiple options possible)*
☐Energy generation
☐Energy consumption
☐Sales of energy/ commercialization
☐Distribution
☐Consultancy (please name the field(s): Click to enter text.)
☐Awareness-raising activities
☐Electric mobility
☐Other(s) (please specify): Click to enter text.
Add details (optional): Click to enter text.

e) Which **energy technologies** are applied in your community? *(multiple options possible)*
☐Solar
☐Wind
☐Hydro
☐Biomass

☐Other(s) (please specify): Click to enter text.
Add details (optional): Click to enter text.

f) What happens to **surplus energy** produced (e.g. compensation, storage, sales)?
Click to enter text.

g) What is the **installed potential** (e.g. kWp) and/or **annual generation** (e.g. kWh/year)?
Click to enter text.

h) What is the **financing mechanism**? *(multiple options possible)*
☐Crowdfunding
☐Member contributions/ shares/ cooperative fund
☐Local authority or municipal support
☐Subsidies
☐Bank loan/ credit
☐Other(s) (please specify): Click to enter text.
Add details (optional): Click to enter text.

Part II: Learnings

a) What are the major **difficulties/ barriers** you have encountered in your project?
Click to enter text.

b) Which aspects do you consider **success factors** with respect to your energy community? What would you recommend anyone establishing an energy community? *(e.g. regarding the organizational structure, technical aspects, involvement of actors, …)*
Click to enter text.

c) Are there any aspects you would like to **improve or change**?
Click to enter text.

Annex B: List of interview partners

Interview partner (IP)	Type of interview partner	Date	Topics covered
IP 1	Representative from the Spanish branch of an NGO with expertise in the field of energy communities	17.12.2021	• Political and legal framework conditions for energy communities • General characteristics/ possible configurations of energy communities in Spain • Recommendation of existing cases
IP 2	Representative from an association for citizen energy (Germany)	18.02.2022	• Political and legal framework conditions for energy communities in Germany • General characteristics/ possible configurations of energy communities • Recommendation of existing cases
IP 3	Representative from a local administration in the Metropolitan Area of Barcelona	12.01.2022	• Conditions for the implementation of local energy communities in the Metropolitan Area of Barcelona • General characteristics of and recommendations for local energy communities in the Metropolitan Area of Barcelona • Recommendation of existing cases
IP 4	Case Study: Member of the Barcelona Local Group of Som Energia	17.01.2022	• Conditions for the implementation of local energy communities in Barcelona • General characteristics/ possible configurations of and

			recommendations for energy communities • Project information and characteristics
IP 5	Case Study: Member of the Poblenou Neighbours' Association	24.03.2022	• Conditions for the implementation of local energy communities in Barcelona • General characteristics/ possible configurations of and recommendations for energy communities • Project information and characteristics
IP 6	Contact person - Energy community project: Barrio solar Zaragoza	28.01.2022	• Project information and characteristics • Difficulties and success factors in the project
IP 7	Contact person - Energy community project: Alumbra	11.02.2022	• Project information and characteristics • Difficulties and success factors in the project
IP 8	Contact person - Energy community project: Sociedad Cooperativa Energética	11.03.2022	• Project information and characteristics • Difficulties and success factors in the project

Annex C: Solar electricity generation estimated with PVGIS

European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

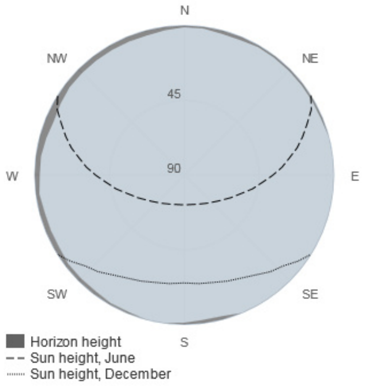
Provided inputs:

Latitude/Longitude:	41.411,2.191
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	22 kWp
System loss:	14 %

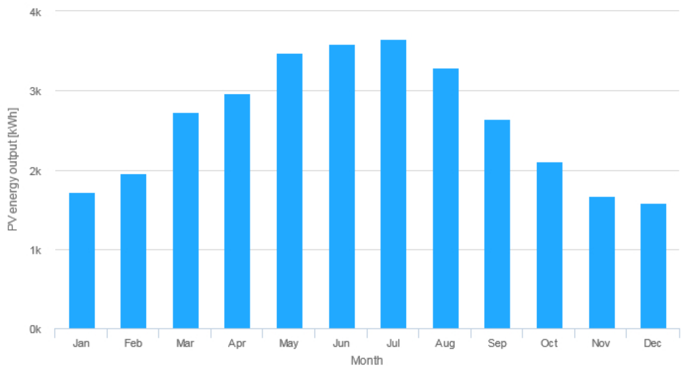
Simulation outputs

Slope angle:	22 °
Azimuth angle:	-45 °
Yearly PV energy production:	31390.14 kWh
Yearly in-plane irradiation:	1822.36 kWh/m²
Year-to-year variability:	780.20 kWh
Changes in output due to:	
Angle of incidence:	-2.98 %
Spectral effects:	0.64 %
Temperature and low irradiance:	-6.75 %
Total loss:	-21.7 %

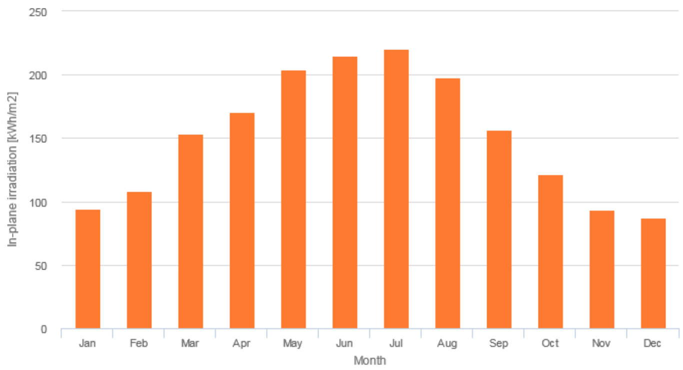
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	1720.7	94.5	180.6
February	1954.5	108.3	204.8
March	2731.4	153.7	212.6
April	2971.8	170.6	232.6
May	3482.3	203.8	262.2
June	3592.3	214.6	135.1
July	3649.5	220.7	164.1
August	3289.9	197.8	146.5
September	2647.7	156.4	122.0
October	2104.7	121.2	247.1
November	1665.1	93.6	197.3
December	1580.2	87.2	148.0

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Report generated on 2022/05/04