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Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future?

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ABSTRACT

The recast of the European Union Renewable Energy Directive (RED II) entered into force in December 2018, followed by the Internal Electricity Market Directive (IEMD) and Regulation (IEMR) as part of the Clean Energy for all Europeans Package. The RED II, that the 28 Member States have until June 2021 to transpose into national law, defines "Renewable Energy Communities" (RECs), introduces a governance model for them and the possibility of energy sharing within the REC. It also provides an "enabling framework" to put RECs on equal footing with other market players and to promote and facilitate their development.

This article defines "renewable energy clusters" that are comprised of complementarity of different energy sources, flexibility, interconnectivity of different actors and bi-directionality of energy flows. We argue that RECs and RE clusters are socio-technical mirrors of the same concept, necessary in a renewable energy transition. To test how these new rules will fare in practice, drawing on a secondary dataset of 67 best-practice cases of consumer (co-)ownership from 18 countries, each project is assessed using the criteria of cluster potential, and for the extent that they meet the RED II governance requirements of heterogeneity of members and of ownership structure. Nine cases were identified as having cluster potential all of which were in rural areas. Of these, five projects were found to be both RECs and RE clusters. The absence of the governance and heterogeneity criteria is observed in projects that fall short of the cluster elements of flexibility, bi-directionality and interconnectivity, while cluster elements occur where the governance and heterogeneity criteria are met. When transposing the new rules into national law we recommend careful attention to encourage complementarity of renewables, RECs in urban contexts and "regulatory sandboxes" for experimentation to find the range of optimal preferential conditions of the "enabling framework".

1. Introduction

Energy communities and consumer (co-)ownership in renewable energy (RE) are essential cornerstones to the overall success of the Energy Transition. When consumers acquire ownership in RE installations they can become prosumers,[1] generating a share of the energy they consume. This allows them to reduce their overall expenditure for energy and simultaneously acquire another source of income from the sale of excess production. Prosumership is expected to be increasingly embedded in energy communities that entail a broad variety of actors [1]. From a technical point of view, these organizational shifts in energy generation, supply and management happen in the context of the growing complexity of energy systems and what we define in this paper to be "renewable energy clusters" (RE clusters). Although both the governance model of energy communities and the engineering model of energy clusters are acknowledged in practice, until now comprehensive regulation is a novelty, and consequently, so are corresponding definitions.

In June 2018, the European Union (EU) agreed on a legal framework for prosumership as part of the recast of the Renewable Energy Directive (RED II), which entered into force in December 2018 [2]. The 28 Member States of the EU now have until June 2021 to transpose the RED II into national Law and from then on consumers, as prosumers, will have the right to consume, store or sell RE generated on their premises.

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[1] The artificial word probably first introduced by Alvin Toffler in his book *The Third Wave* (1980) stems from the Latin; as early as 1972 Marshall McLuhan and Barrington Nevitt suggested in their book *Take Today*, (p. 4) that technological progress would transform the consumer into a producer of electricity.

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(i) individually, that is, households and non-energy small and medium sized enterprises (SMEs) and collectively, for example in tenant electricity projects (Art. 21 RED II), or
(ii) as part of Renewable Energy Communities organised as independent legal entities (Art. 22 RED II).

The RED II is part of the Clean Energy for all Europeans Package of the European Union[2] and its rules are embedded in those of the 2019 Internal Electricity Market Directive (IEMD) [3] and Regulation (IEMR) [4], both of which reached political agreement in the inter-institutional negotiations (so-called Trilogue) on 18 December 2018. "Energy communities" are mentioned and defined in both the RED II and the IEMD and so is the concept of "energy sharing" within them. The recast of the renewables directive focuses on the promotion of RE and thus speaks of "Renewable Energy Communities" (RECs), whereas the directive on the internal electricity market of the European Union as the more general legal act addresses "Citizen Energy Communities" (CECs). While the purpose of IEMD/R is the completion of the internal market, that of RED II is to specifically support the deployment of renewable energy sources (RES) for *energy production including electricity* and to foster acceptance for renewables among Europeans. Both directives expressly see the consumer "at the heart of the energy markets" defining them – individually or jointly – as "Active Consumer" (IEMD) respectively as "Renewable Self-consumer" (RED II).

1.1. Renewable energy clusters – the future of the energy systems

Energy communities are nothing new. In remote places and on islands, where access to fuels is scarce and costly, they have existed long before the Energy Transition when the trend for decentralised RE production became mainstream. But with the rise of decentralised RE-production and various forms of consumer (co-)ownership in renewables, energy communities have the potential to become a standard model on the energy markets. Similarly, what we conceptualize here as "energy clusters" are also not new. They have been developed in industrial production settings to cut cost and increase energy efficiency and in military settings to ensure autarky and supply security mostly in micro grids. But unlike in the fossil and nuclear energy world, that is characterised by large, centralized generation and a unidirectional producer-consumer duality, the RE clusters emerging now in the context of the Energy Transition are built on the complementarity of different energy sources, flexibility, as well as interconnectivity of all sorts of different actors – be they small or large, professional or not – requiring bi-directionality of energy flows.

In the technical literature, analogous concepts to the conceptualization of RE clusters in this paper include: "hybrid renewable energy systems", made up of solar PV at the household level, wind power at the community level, and battery storage [5]; "spatiotemporal modelling of RES", an emerging research field that aims at supporting and improving the planning process of energy systems with high shares of RES [6]; "multi-energy systems" (MES) that consider the optimal interaction of electricity, heat, cooling, fuels, transport, at various scales, for example, district, city or region [7]; "autonomous polygeneration microgrids", to address the power, fuel for transportation in the form of hydrogen, potable water through desalination and space heating and cooling needs of remote areas [8]; or a "sustainable energy district" in an urban area, that considers renewable electricity from solar PV and wind micro-generation alongside combined heat and power units, and traditional boilers connected to the public grid [9]. While these concepts are closely related to that of RE clusters, they do not sufficiently reflect the heterogeneity of actors and the related question of governance. Our paper extends this literature around defining RE clusters and addresses this socio-technical gap by introducing the mirror concept of energy communities, illustrating how these are two sides of the same model.

In this context, RECs can be seen as the prototype governance model of an emerging form of energy systems, that is, RE-clusters. This concept for the lawful control over and administration of (local) energy generation, supply and management is the governance side of the technical/engineering concept for RE clusters. Such clusters will typically include demand flexibility and EE measures, storage and peer-to-peer trading between prosumers and/or producers within energy communities, and between energy communities and the market. For existing (e.g., smart meters) and emerging technical solutions (e.g., distributed ledger technologies like the blockchain) to be functional, behavioural changes of the consumer are indispensible. In comparison to conventional technology installation programs characterised by high barriers to entry for consumers and a lack of scalability, consumer engagement programs leverage innovative engagement strategies more effectively [10]. However, while the latter have generally proven to dramatically increase both the scale and cost-effectiveness of consumer-funded efficiency investments, the installation cost of new technologies to the consumer (especially "smart grid" related technologies) often impedes their implementation. Therefore, it is crucial to couple technological solutions with good governance, as acknowledged by the European legislator in RED II and IEMD/R.

1.2. The challenge for (renewable) energy communities

The transposition of these comprehensive rules – in particular those on energy communities – requires developing, implementing and rolling out business models that broaden the capital participation of consumers in all 28 Member States while permitting co-investments of different type of actors. Amongst others, Member States have to adopt an "enabling framework" for prosumership, in particular for RECs. Defining citizen's rights and duties, the directive links prosumership to such different topics as fighting energy poverty, increasing acceptance, fostering local development and incentivising demand-flexibility. The IEMD amongst others provides energy communities with a level playing field vis-a-vis other market participants (see Art. 65 IEMD). RED II on the other hand additionally has an important vertical element as it ensures for example that RECs can compete for support "*on an equal footing with other market participants*" and calls on the Member States to "*take into account specificities of renewable energy communities when designing* support *schemes" (Art. 22 para. 7)*. While the framework under IEMD is primarily a regulatory framework, that of RED II has the explicit aim "*to promote and facilitate the development of RECs*" (see Art. 22 para. 4, sentence 1) including preferential conditions or incentives. In summary, RECs are a specific form of CECs benefitting from an "enabling framework" that promotes and facilitates their development.

But European energy law with regard to energy communities does not rule out other private law citizens' or consumer-oriented initiatives that are facilitated by and implemented with the participation of the public administration in the Member States [11 p. 30]. These initiatives would not have to comply with the governance model described above and could be controlled and led by the incumbent professional actors on the energy markets. Such initiatives, however, would not benefit from the privilege of energy sharing of IEMD, and in particular the preferential conditions or incentives foreseen in the "enabling framework" under RED II. Therefore, the attractiveness and coherence of this "enabling framework" will be key to the question of whether energy communities that comply with the criteria of RED II and IEMD will live up to the challenge of fulfilling the required functions of energy clusters (more on this in the theory section below). The instrument to advance RECs can be described as an opt-in mechanism [12] that creates peer-pressure: the more successful RECs are on the new energy markets, the more attractive this new business model becomes to the incumbents,

[2] On 30 November 2016 the European Commission presented a package of measures to keep the EU competitive as the energy transition changes global energy markets with four main goals, i.e., energy efficiency, global leadership in RE, a fair deal for consumers and a redesign of the internal electricity market.

and the more acceptable the governance model, with its emphasis on the prosumer and the active consumer.

1.3. Research questions and approach

The implementation of energy communities is influenced by a broad variety of governance patterns that involve different combinations of (innovative) organizational and contractual arrangements, (local) identities and (common) interests [13]. It is the combination of these factors in a particular setting that hinders or facilitates the successful creation of the energy community in the RE-cluster context. Geographic, technological, demographic and cultural diversity of RE-projects combined with the factors mentioned above leads to complexities that prohibit "one size fits all" solutions. Of course, the "enabling framework", its incentives and preferential conditions should as much as possible, address these factors, that may take a different shape across the 28 Member States. While identity and interest are deeply rooted in geographies and cultures, organizational and contractual arrangements are a political and procedural factor that is more flexible and can be adapted to the former two. We consider key aspects of their adaptation to be the openness to different local actors, the potential for energy sharing and the ownership structure. To identify patterns of success and failure – following a socio-technical approach – these key factors and their interaction with each other require examination.

To assess whether or not the regulatory and governance model for energy communities put forward by the Clean Energy Package is to become a model for legislation worldwide – like the year 2000 German RE law which was replicated across the globe [14] – several questions need to be answered:

(i) Drawing on the experience of already existing best practice energy communities that function in a RE-cluster context, what are the necessary technological, economic, and legal conditions for success?

To identify these conditions, we analyse a dataset of 67 best practice cases from 18 countries covering Europe, North and South America and Asia using: (a) key categories for RE-clusters like complementarity of energy sources, interconnectivity of actors, bi-directionality of energy flows and flexibility options; (b) whether they are open to different actors, i.e., the heterogeneity of members or shareholders; and (c) their governance and ownership structure.

(ii) What type of incentives/preferential conditions are relevant for facilitating the setting up and functioning of RECs with RE-cluster potential? And what incentives/preferential conditions under a future "enabling framework" could be suitable to entice professional energy companies to partner with energy communities?

As with a rising share of RE in the energy mix, complex RE-cluster projects are expected to become the rule and not the exception, we assume that incumbent actors from the professional energy sector will still have an important role to play. Therefore, we investigate the selected cases as to which incentive factors were relevant for success and which could be suitable to involve also "commercial" players usually not interested in energy communities.

(iii) Against this background are the new rules fit to promote the wide deployment of RECs in the context of RE-clusters and what recommendations can be made with regard to their transposition in to national law?

Of course, any existing RE-projects from the dataset operating as energy clusters or coming close to doing so do not necessarily comply with the requisites of the Clean Energy Package since they emerged under entirely different regulatory frameworks. However, given that they had to cope with the same governance, institutional and technological challenges, they are a good benchmark for the new rules of the RED II and the IEMD/R. In particular, as the transposition leaves significant room for manoeuvre to the national legislators, recommendations are important.

2. Material and methods

For the analysis we draw on a dataset of 67 best-practice examples of consumer (co-)ownership[3] reported in the Palgrave Macmillan publication "Energy Transition: Financing Consumer Co-Ownership in Renewables" [15]. In this publication, consumer (co-)ownership is defined as "participation schemes that (a) confer ownership rights in RE projects (b) to consumers (c) in a local or regional area" [16 pp 7–8]. The cases are from 18 countries covering Europe, North and South America and Asia.[4] In light of the potential for replication of the regulatory framework beyond Europe, and to confirm the existence of projects that fit the criteria elsewhere, the extra-European cases present in the dataset were included in the analysis.

To answer the first research question regarding the necessary technological, economical, legal conditions for success, we test the dataset for the following criteria:

2.1. Energy cluster potential

Both the REDII and IEMD mention the concept of energy sharing in relation to RECs/CECs. This will allow energy communities to share energy amongst participating entities without brokerage of a third party even when using the public grid. This is crucial for the functioning of *energy clusters.* To fulfil this function, certain technical aspects in a project need to be met: interconnectivity and bi-directionality between installations or installations and the market; complementarity due to a variety of RES-types in the portfolio; and flexibility options (storage, demand response, etc.). These aspects are more fully discussed in Theory section 3.1.

2.2. Heterogeneity of members

Eligible members for RECs are natural persons, small and medium-sized enterprises and local authorities while CECs are in principle open to all entities. Both the IEMD and the RED II thus support heterogeneity of members, which follows from the purpose and guiding principle for both types energy communities "*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*". This criterion is elaborated on more fully in Theory section 3.2.

2.3. Governance and ownership

The RED II prescribes that to qualify as a REC, the effective control, that is, the majority of voting rights, should be held by members based in the proximity of the installations. Furthermore, the autonomy of the REC from single shareholders is to be upheld by the principle that no single shareholder owns a controlling stake, that is, as a rule more than a third of the shares. Similarly, but less strict, the IEMD precludes entities engaged in large scale commercial activity and for which energy

[3] The notion of (co-)ownership is used here not in the technical sense of joint ownership but to indicate that there may be other owners next to the consumers amongst the shareholders such as municipalities or conventional investors.

[4] That is, CZ, DK, FR, DE, IT, NL, PL, ENG, SCT, ES, CH, CAL, CAD, BR, CL, IND, PAK, JAP; these countries were analysed following a consistent pattern including the energy mix, policies supporting consumer (co-)ownership, energy poverty, the regulatory framework, best practice, financing conditions, obstacles and perspectives to enable a like-to-like comparison.

constitutes the primary activity as well as medium and large-sized enterprises from the shareholders effectively controlling the CEC; consequently such entities may only have minority shareholding in the RE-project. This criterion is elaborated on more fully in Theory section 3.2.

The 67 RE-projects were assessed according to the three criteria. This resulted in the selection of best-practice energy communities for further analysis.

To answer the second research question regarding the conditions and incentive factors that were relevant to the success of these RE-projects, patterns in the development of the projects were discerned. Where the original dataset did not provide sufficient information regarding above-mentioned criteria, complementary research was carried out. Drawing on the discussion and conclusions from this analysis, we assess the third research question whether the rules of the new EU framework of RED II and IEMD/R are fit to promote the wide deployment of RECs in the context of RE-clusters. We also formulate recommendations with a view to the pending transposition of RED II and IEMD into national law to national policy makers.

3. Theory

3.1. The importance of RE clusters

Current forecasts show that to meet the targets set out by the Paris Agreement, renewable electricity would need to make up at least 40%, but up to 63%, of new electricity supply by 2040 [17]. Some argue that 100% RE is a desirable and achievable goal [18] and aligns with a more democratically organized energy system [19]. However, existing electricity grid technologies can only accommodate somewhere between 20% and 40% from renewables [20,21]. To reach a larger share of renewable electricity, new grid designs that provide for more balancing and flexibility options are required [20,21]. And, indeed, in recent years, as grid-related information, new grid management technologies and materials have increased so-called smart grids allow for better coordination among the elements of generation, demand, and distribution [22]. Against the background of this development, matching supply to demand leads to three major shifts in energy infrastructure [23], namely “(1) the possibility of super grids that can transport large volumes of power over long distances to demand centres; (2) an increase in grid flexibility to match intermittent renewable power generation to demand that varies with time; (3) an increase in distributed infrastructures.” In a context of urbanization, combined with the decentralization of energy activities, tailored approaches that fit the landscape and load density are increasingly necessary [6,23].

In this paper, we outline a conceptualization of RE clusters, that address (2) and (3) by combining four interrelated elements that form the principles of design for tailoring to context specificity. These are: *flexibility*, *interconnectivity*, *bi-directionality* and *complementarity*. In this paper, we argue that the governance model of RECs and CECs as defined in the RED II and IEMD/R are the mirror image of this technical concept that will allow for increased social acceptance of the architecture and logic of a RE future. *Complementarity* of RE is a fundamental strategy to increase the share of RE in a given energy system. It is enabled through *interconnectivity* of multiple installations. Combining complementarity with grid flexibility options, such as storage, demand response, and active grid management, allows the share of RE in a given system to increase even more [e.g., 5,24. We discuss the four general functional aspects as they relate to RE.

3.1.1. Flexibility, interconnectedness and bi-directionality in RE clusters

Flexibility options allow for increased balancing of renewables on a grid. They often rely on smart meters[5] and include prosumership, aggregation,[6] virtual power plants,[7] micro grids,[8] peer-to-peer trading,[9] storage[10], and increasing the time sensitivity of loads through responsive load and demand response[11] [21]. At the same time these options rely on the presence of *interconnectivity*, that allows the inclusion of all sorts of different actors – be they small or large, professional or not, or between markets – and *bi-directionality* of energy flows that encourage dynamic, time-sensitive participation in *flexibility* options, particularly prosumership.

Energy clusters can also include other forms of energy than electricity, which also rely on the principles of flexibility, interconnectivity and bi-directionality. These include distributed energy that may provide fossil fuel or biomass back up generation for RE-electricity, district energy (e.g., heating and cooling) and combined heat and power. Distributed energy is defined as the production of heat or electrical power near the end of the distribution network, and other practices that can balance loads at a similarly local scale [25]. District energy, or thermal networks, consist of multi-building heating and cooling, in which heat and/or cold is distributed by circulating either hot water or low-pressure steam through underground piping [26]. District networks

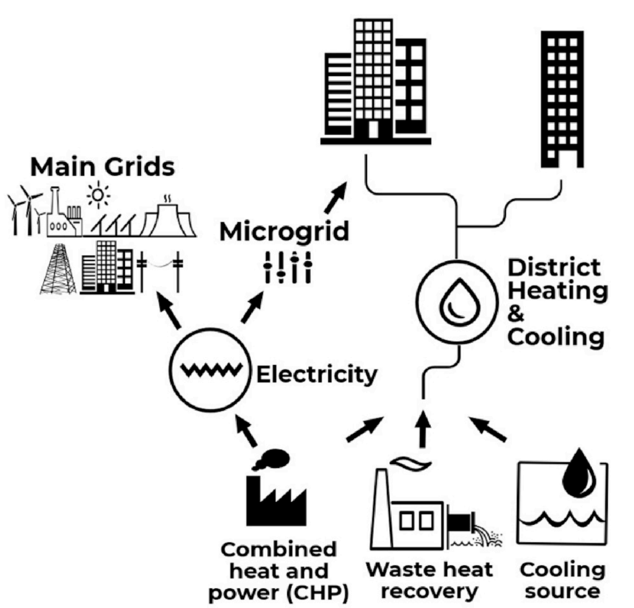

Fig. 1. Elements of RE-Clusters.
Source: Own elaboration.

[5] Smart meter: defined in Art.2 pt.23 IEMD 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”.

[6] Aggregators acts in the market to manage demand response of multiple loads [21].

[7] Virtual power plant is “understood in Europe as a system resulting from the aggregation of RES-based energy generation plants to supply a desired demand in a reliable manner” [6].

[8] A micro grid is 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” according to the U.S. Department of Energy [27].

[9] Art. 2 (18) RED II defines “peer-to-peer trading” as “the sale of renewable energy between market participants by means of a contract with pre-determined conditions governing the automated execution and settlement of the transaction, either directly between market participants or indirectly through a certified third-party market participant, such as an aggregator.”

[10] The role of storage is to store and deploy variable energy as dispatchable generation during periods of high demand in an electrical grid [23].

[11] “Responsive load and demand response innovations provide flexibility by enabling power consumption to vary in response to supply-side variability and grid conditions, and thus allow power demand to play a role in balancing variable renewables” [21].

incorporate an underground system of piping from one or more central sources to industrial, commercial and residential users. The heat delivered to buildings can also be used for air conditioning by adding a heat pump or absorption chiller [26]. Therefore, district energy involves interconnectivity and flexibility of the distribution of heating and cooling on a grid; it often relies on a range of actors, as it can be fuelled by industrial waste heat (e.g., sewage, industrial processes), solar, biomass, geothermal, waste-to-energy (WTE), combined heat and power (CHP) [26] or deep lake cooling water 28. CHP simultaneously produces both heat and power [21] as it captures waste heat from power production, and can be fuelled by fossil fuels or biomass, biofuels, and heating load can be combined with solar hot water heating or waste heat and distributed through district energy systems [26].

In the following sections, the interaction of these elements and their relevance to the challenges of the Energy Transition are described.

3.1.2. Complementarity of RES to improve the volatility of RE generation

The main sources of RE are solar PV, wind, biomass, biogas, and hydroelectric. While the main goal of energy provision is to maintain reliability for energy users and minimize their economic losses [23], many renewable forms of energy production are variable on both short and long time scales (hourly, daily, monthly) [29]. On a temporal basis, the complementarity (asynchronicity of variable energy production that smooths out total or combined energy production over time) of a portfolio of RES, be they wind and hydroelectric [30], wind and solar PV [24,29,31], and wind, hydroelectricity and solar PV [32], is found to have multiple benefits that reduce the barriers to incorporating larger shares of variable sources of RE into an electricity grid.[12] For example, many studies have demonstrated the economic feasibility and reliability of standalone hybrid solar PV and wind installations [29].

However, the literature demonstrates other benefits of complementarity of RE, mainly the ability to integrate a larger share of renewables to a grid and/or improve cost effectiveness of RE systems. In the case of developing countries, Zhang et al. [32] found that the original transmission channel of hydropower can carry a relatively sustained and stable power supply for the grid with the combined use of cascaded hydropower (14,700 to 15,300 MW) storage capacity that can compensate for large-scale wind (5,200 to 6,800 MW) and photovoltaic power (4,950 to 13,050 MW). Complementarity is also shown to improve with the addition of flexibility options, and improves the economics of the flexibility options themselves. Ramirez Camargo et al. [5] have found in the case of solar PV and battery systems to supply electricity for singular self-sufficient households in intermediate density and thinly populated areas, the inclusion of small wind turbines to a cluster of 10 households decreased total system costs and the required storage capacities. Sun and Harrison [24] demonstrate that when solar PV and wind resources are combined rather than considered as singular resources, this complementarity leads to more effective use of network capacity by renewables, and increases the amount of RE generation capacity a network can host and the total energy export; these improved outcomes are further increased with flexibility options of active network management technology; and increased even further with governance, as carefully designed curtailment rules.

3.1.3. Energy density and spatial reorganization of renewable energy systems

The transition to a larger share of RE also requires a spatial reorganization of our energy systems, cityscapes and landscapes [6,33–35]. The decentralization of RE systems will not be evenly distributed [33,34] — there will be different technologies and combinations for different contexts [6,36], and this uneven distribution will coincide with different populations, with a range of socioeconomic statuses, cultures, local politics and local economic development patterns, in different ways [23] .

One key-contributing factor to this uneven distribution is the diverging pattern of energy density per unit area (W/m^2) of energy supply and energy demand. Alongside temporal variation of renewable power, renewable sources can often be several orders of magnitude less energy dense per area unit (W/m^2) than conventional thermal power generation (nuclear and fossil fuel) [37]. This lower energy density means that renewable and distributed generation sets new pressures on the use of space, and requires the coupling of spatial and energy planning [6]. At the same time, another key trend in the consideration of the Energy Transition is urbanization, a key factor in growth [38] that will impact energy demand centres [23,39], as will the electrification of transportation [23]. Energy demand depends on land use planning and the relative location, shape, and built density of industrial, commercial, and residential centres [40–42]. The spatial density of energy demand in urban centres can be several orders of magnitude higher than the spatial density of production of RE [43]. Hoicka and MacArthur [23] point out that if growth of electricity demand in a dense downtown core outpaces the size of the transmission lines, it can put pressures on delivering supply, as bringing sufficient electricity or energy to an urban centre can lead to congestion and constraints on the electricity grid.

That less spatially energy dense RE puts pressures on space, and more spatially energy dense demand centres may increase pressure on the grid's ability to deliver electricity offers some explanation of how urban and rural populations interact differently with energy. Tailored solutions in urban centres tend to focus on combined heat and power and district energy, solar PV, and small size to no wind power generation [9], as well as participation in EE, demand response, and other flexibility options [23]. Meanwhile, tailored solutions in rural settings assess temporal complementarity across space to determine the best regions to promote different technologies. For example, combinations of wind and solar PV [5]. The location of power installations affects the optimization of resource use and costs in an interconnected system, and therefore, assessments for complementarity between resources can be spatial as well as temporal, in order to find the best combination of power plant locations and resources for an energy system [30]. In the case of wind-solar hybrid, Ren et al. [28] found that complementarity can be improved with the dispersion of wind farms, but not of solar power. They also found that the complementarity between wind and solar PV was more significant than the spatial complementarity of a single source between regions [29]. Highly networked models with multiple autonomous suppliers of energy will have a decentralization of capacity and supply decisions, although regional uptake is expected to have wide spatial variation and uneven development spatially [33]. The matching of supply and demand both spatially and temporally requires considerations of demand growth, grid utilization and constraints, the optimization of the use of space, flexibility options, and the social acceptance of flexibility, demand, generation and distribution technologies. This illustrates why tailored approaches, that we define as RE clusters, are increasingly required to manage local energy issues, whether on-grid, off-grid, urban, or rural and depending on land-uses [6]. What is necessary are institutions to support these forms of heterogeneity in order to increase RE across communities and energy systems.

3.2. Defining energy communities and energy clusters under IEMD and RED II

In this paper, energy communities and energy clusters are mirror images, governance and technological, of the same concept, entailing flexibility, bi-directionality and interconnectivity options between prosumers and producers of energy and the market, allowing energy sharing of a portfolio of RES, that can enhance complementarity. The previous sections described how the combined elements that make up this conceptualization of energy clusters are increasingly recognized as a crucial component for the advancement of a transition to a greater share

[12] Reliability is also increased with the combination of with more dispatchable resources, such as biomass/biogas (check dispatchability) or fossil fuels.

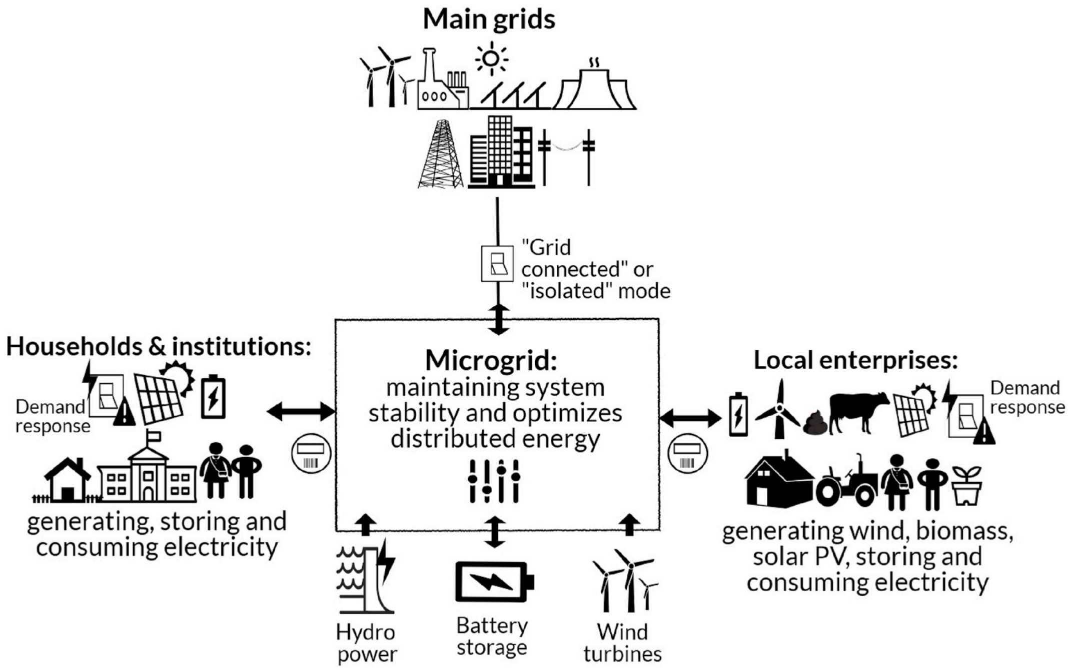

Fig. 2. Elements of RE clusters.
Source: own elaboration.

of RE, to address technological, infrastructural, and economic pressures. The following sections outline how (renewable) energy communities may address the social, political and institutional pressures.

3.2.1. RED II, prosumers and renewable energy communities

As mentioned in the introduction, RED II offers consumers the right to prosume, be they physical persons, organizations and enterprises individually[13] or collectively organised in "*Renewable Energy Communities*" (RECs).[14] RECs have an own area of operation not falling under the IEMD/R as far as other types of energy, that is, not electricity, are concerned. In this regard, the possibility to benefit from small-scale back-up conventional generation is an important element for micro-grid solutions, whether on or off-grid. The "right to prosume" entails the right to generate RE, including for their own consumption and to store or sell excess electricity production including via power purchase agreement (PPA), suppliers and peer-to-peer trading, receiving market based remuneration and guarantees access to all suitable energy markets directly or via aggregation. Most importantly, in the cluster context this also includes the right for RECs to share RE produced on their site/sites (bi-directional and interconnected) within that community. To promote RE, the RED II contains an "enabling framework" for these consumers, who have traditionally received energy uni-directionally from the main grid, to become prosumers, by assuming bi-directional and interconnected relationships of energy production and consumption between the prosumer and other consumers, prosumers, producers, and the market. Recital 71 RED II stipulates "*Renewable energy communities should be able to share between themselves energy that is produced by their community-owned installations.*" By providing an "enabling framework" that includes the possibility of sharing energy[15] among consumers, producers, and prosumers locally, RECs promote bi-directional and interconnected energy production and consumption, all indispensable elements in RE clusters.

Electricity sharing is defined in recital (46) IEMD and enables members of RECs "*to be supplied with electricity from the generation plants within the community without being in direct physical proximity or behind a single metering point.*" This includes the right to virtual net-metering resulting from an earlier passage of the same recital that describes the specific link to information and communication technologies (ICT): "*Citizen energy communities should not face regulatory restrictions if they apply existing or future ICT to share electricity from generation assets within the community between its members or shareholders based on market principles, for example by offsetting the energy component of members using the generation available within the community, even over the public network, provided that both metering points belong to the community*". Art. 22 para 4 RED II stipulates that the "enabling framework" to promote and facilitate the development RECs "*shall ensure, inter alia, that: … (e) renewable energy communities are not subject to discriminatory treatment with regard to their activities, rights and obligations as final customers, producers, suppliers, distribution system operators, or as other market participants*" stressing their right to own and operate distribution systems [44].

3.2.2. RED II and IEMD/R encourage flexibility, interconnectivity, and bi-directionality

The new opportunities for flexibility brought along by the Energy Transition – as well as the accompanying challenges – are reflected in both RED II and IEMD/R. The new rules encourage energy sharing and the elements of flexibility, interconnectivity and bi-directionality above all through rules on smart meters, micro grids and peer-to-peer trading. Arts. 19–22 IEMD re-launch the rollout of smart metering with the

[13] Pursuant to Art. 2 RED II as "Renewable Self-consumer" is a final customer that generates renewable electricity for its own consumption operating within its premises (also SME if not primary commercial/professional activity) and "Jointly acting Renewable Self-Consumers" (minimum of 2) are located in same building or multi-apartment block.

[14] Pursuant to Art. 2 RED II a REC is a legal entity based on open & voluntary participation, autonomous, and controlled by shareholders or members, located in proximity of the RE projects, owned & developed by that legal entity.

[15] Art 16 para 3 IEMD obliges Member States to ensure that citizens energy communities: "*… (e) are entitled to arrange within the community sharing of electricity that is produced by the production units owned by the community…*".

relevant provisions applying to future installations and to installations replacing older smart meters. Art. 19 para 2 IEMD stipulates that "*Member States shall ensure the implementation of smart metering systems in their territories that shall assist the active participation of customers in the electricity market.*" However, this may be subject to a cost-benefit assessment according to the principles outlined in Annex III of the directive. Nevertheless, pursuant to Art. 21 IEMD, even where smart metering is negatively assessed as a result of this cost-benefit assessment, consumers as final customers – while bearing the associated costs – are entitled to have a smart meter installed or upgraded. The underlying rationale is to promote energy efficiency and to empower final customers with the aim to optimise the use of electricity. The new legislation accomplishes this, amongst others, by introducing interoperable smart metering systems in particular with consumer energy management systems and smart grids, providing energy management services and developing innovative pricing formulas (compare Art. 19 para 1 IEMD).

Furthermore, Art. 16 para 2 (b) IEMD foresees for Member States the possibility to grant energy communities the right to own, establish, purchase or lease distribution networks and to autonomously manage them. In this case, that a REC acts as a network operator it becomes an addressee of the regulation framework and in particular of the conditions set out in Art. 16 (3) IEMD. However, as recital (47) states the IEMD allows the Members States to grant such networks the same privileges as for closed distribution networks in the meaning of Art. 38 IEMD, in particular exemptions from procurement and approval requirements. This is a specific exception for energy communities since Art. 38 IEMD as a rule excludes the qualification as closed distribution networks if household customers are supplied. Finally, Art. 2 (18) RED II defines "peer-to-peer trading" as "*the sale of renewable energy between market participants by means of a contract with pre-determined conditions governing the automated execution and settlement of the transaction, either directly between market participants or indirectly through a certified third-party market participant, such as an aggregator.*" The underlying distributed ledger technologies, for example blockchain, rely on the concept of tracking single transactions simultaneously on a shared ledger that the parties to the transaction trust to be accurate and permanent [45]. The Internet, being inherently decentralised in its physical structure, is the natural information grid for distributed ledger technologies. The majority of pilot and research projects are centred on direct exchanges of energy between customers, that is, "peer-to-peer" marketing of energy and offering electricity based on crypto currencies [[46]]. However, the fields of application include managing the trade of RECs and the charging of electric vehicles or optimizing internal and business-to-business processes within RECs.

3.2.3. How RED II and IEMD/R allow for complementarity

The new rules also offer the potential for complementarity of RE in RECs in three ways: (a) allowing multiple resources (b) through flexibility option of peer-to-peer trading among prosumers and producers that supports a range of resources that can be complementary with (c) the entitlement to own and manage distribution networks, or delegate their management. Further enabling factors of complementarity are the preferential rules for RECs for curtailment, priority dispatch, trading in day-ahead and intraday market as well as for access to balancing markets. Art. 12 IEMR defines the principle of priority dispatch for RE plants with an installed electricity capacity of less than 400 kW and for demonstration projects for innovative technologies.[16] However, priority dispatch is to be phased out with a threshold of less than 200 kW for RE plants commissioned after 1 January 2026 the. With regard to non-market-based redispatching[17] Art. 13 para 6 IEMR makes an exemption for self-generated renewable electricity not fed into the grid allowing downward redispatching and possible curtailment only if no other solution is available to resolve grid security issues; defines an exemption from. Furthermore, with regard to RECs Art 8 para. 3 IEMR stipulates "*Nominated electricity market operators shall provide products for trading in day-ahead and intraday markets which are sufficiently small in size, with minimum bid sizes of 500 Kilowatt or less, to allow for the effective participation of demand-side response, energy storage and small-scale renewables including directly by customers.*"

Apart from the general catalogues of rights and duties, there are also balancing rules with specifications and exemptions for energy communities. According to Art. 5 IEMR, market participants have balance responsibility, i.e., they are responsible for any imbalances they cause in the electricity system and are either themselves "*balance responsible parties*" or may contractually delegate their responsibility. However, Member States may allow exemptions for RE plants with an installed electricity capacity of less than 400 kW (and for RE plants commissioned after 1 January 2026 of less than 200 kW) provided that financial responsibilities for imbalances are fulfilled by another party. Non-discriminatory access for renewable electricity also to balancing markets is guaranteed by Art. 6 IEMR, including electricity generated from variable RES, demand response and energy storage, be it individual or through aggregation.

3.2.4. The new governance model and incentives and preferential conditions for RECs

RED II and IEMD put forward a new Europe-wide governance model for energy communities (see Table 1). Both types of energy communities provide an enhanced focus on environmental, economic or social community benefits rather than on profits, and limit the effective control of the energy community to their local members or shareholders as main beneficiaries. RECs do this by tying control to the criteria of locality and geographic proximity of their members or shareholders. CECs, on the other hand, limit control by the size of the shareholders and their commercial activity, and excludes those for which energy constitutes the primary area of activity.

With regard to incentives, RED II puts RECs in a better position towards public authorities and other electricity undertakings providing a catalogue of explicit rights granted specifically to them and defining the principles of non-discriminatory and proportionate treatment. This additional scope of RED II is of particular importance in Member States where RECs do not yet exist, for example, in Eastern Europe. This obligation of Member States in Art. 22 RED II includes ensuring that "*unjustified regulatory and administrative barriers are removed*", "*tools to facilitate access to finance and information are available*", "*regulatory and capacity-building* support *is provided to public authorities in enabling and setting up RECs, and in helping authorities to participate directly*" and that they "*take into account specificities of renewable energy communities when designing* support *schemes in order to allow them to compete for* support *on an equal footing with other market participants.*" To avoid the possibility that utilities or financial investors set up RECs in order to benefit from this consumer-oriented "enabling framework", RED II limits corporate control to the above-mentioned qualified categories of entities and excludes undertakings whose participation in a REC constitutes their primary commercial or professional activity.

The attractiveness and coherence of this "enabling framework" spelled out by each member state according to national specificities will be key to the question of whether energy communities that comply with

[16] Pursuant to Art. 2 pt (24) IEMR "*a project which demonstrates a technology as a first of its kind in the Union and represents a significant innovation that goes well beyond the state of the art.*"

[17] Market-based redispatching with resources selected amongst generation, storage or demand facilities and being financially compensated is the rule while non-market-based redispatching is a default solution.

Table 1
The new governance model for energy communities under RED II and IEMD.

Criteria	Renewable Energy Communities pursuant to RED II	Citizen Energy Communities as defined in IEMD
Eligibility	• natural persons, • Small and medium sized enterprises, • local authorities, incl. municipalities;	in principle open to all types of entities;
Primary Purpose	*"environmental, economic or social community benefits for its shareholders/members or for local areas where it operates, rather than financial profits";*	
Member-ship	voluntary participation open to all potential local members based on non-discriminatory criteria;	voluntary participation open to all potential members based on non-discriminatory criteria;
Ownership and control	• effectively controlled by shareholders or members that are located in the proximity of the RE project; • is autonomous (no individual shareholder may own more than 33% of the stock).	• effectively controlled by shareholders or members of the project; • limitation for firms included in shareholders controlling entity to those of small/micro size (not medium); • shareholders engaged in large scale commercial activity and for which energy constitutes primary area of activity excluded from control.

Source: Own elaboration.

the criteria of RED II and IEMD will fulfil the desired functions of our concept of energy clusters.

4. Results

The results of the analyses for cluster potential of the cases that were described in the methods section are presented in Table 2–6. The results demonstrate that in the evaluation of the 67 cases, only five can be qualified as already operating as fully-fledged RE clusters and RECs (Tables 3 and 6). In 31 of the original case studies, the project includes solar energy (photovoltaics and/or thermal). Furthermore, the dataset covers a wide range of RES and sustainable energy solutions: biomass heating plants with wood chips, biogas plants with CHP output, on-shore and off-shore wind turbines, storage systems, bio fuel production, methane production, heat pumps, run-of-river hydroelectric, solar street lighting, micro and smart grids and finally district heating networks.

4.1. Non-qualified RE projects

As we identify nine cases having cluster potential or already function as clusters (Table 4, 5 and 6), the remaining 58 do not show cluster potential for a variety of reasons: some projects meet the heterogeneity and governance requirements, but do not come close to meeting RE-cluster requirements. In others, the opposite is true, with technical requirements partially met but projects being dominated by commercial actors or only owned by one shareholder. A diversification of participating actors in 47 of the dataset's cases would be needed to meet RED II and IEMD qualification criteria in terms of governance and heterogeneity. Many of the evaluated cases are projects where only one actor that is not a cooperative or a municipality has ownership and thus do not meet the heterogeneity criterion. In a number of the projects a large energy firm not based in the proximity of the installations has an ownership stake exceeding 33% or a majority stake violating the governance criterion. This also obstructs the autonomy condition set out in REDII and the prohibition of large energy firms to control a CEC per IEMD. Furthermore, many projects feature only one type of RES, not allowing them to meet the complementarity element, and mention no flexibility options, preventing them from functioning as fully-fledged RE clusters in our understanding of the term.

Table 2
Number of consumer co-ownership projects that meet each criterion.

	Criterion 1. Cluster potential	Criterion 2. Heterogeneity	Criterion 3. Governance & Ownership
Number of projects	9	20	7

4.2. Projects with RE cluster potential that do not meet REC requirements

Projects with strong RE cluster potential, but that do not meet REC requirements, are described in Table 4. In two cases, the Spanish Barcelona Energia and the Czech bio-energy centre in Kněžice the sole shareholderis the municipality , therefore not meeting the heterogeneity and governance requirements. Further, while these contain multiple RES that contribute to complementarity and have bi-directionality and interconnectivity, they do not include flexibility. These projects in Table 4 would require the inclusion of the element of flexibility in the RE cluster criterion, and much larger adaptions to heterogeneity and governance to meet the requirements of RECs.

4.3. RE projects functioning as or close to RE clusters but not fully meeting REC requirements

Two cases, namely the micro-grid in Huatacondo, Chile, and the project in Le Mene in France scored well (Table 5). The project in Huatacondo, Chile, meets all four elements of the cluster criterion of the technical cluster requirements, but is currently dominated by a commercial actor, although, ownership is set to change hands. The project in Le Mene in France met most of the criteria for energy clusters; it has complementarity of RES, bi-directionality, and interconnectivity, but is missing flexibility. In their current state, neither complies with either the heterogeneity or governance criterion for RECs, but with relatively small adaptions to all three criteria (Table 5), both could meet full REC and RE cluster criteria.

4.4. RECs that are model or almost model RE clusters

From the evaluation of the 67 best-practice cases in the data set, five projects are found to adhere best the evaluation criteria, thus qualifying as RE-communities that actually are RE-clusters. These are: the micro-grid project on the Dutch island of Ameland, the biomass and PV project in the municipality of Hostetin in the Czech Republic, the project in Odhanturai, rural India, the cooperative E-Werk Prad in Italy and, finally, the electricity grid on the Isle of Eigg, Scotland. How they match the three criteria is shown in Table 6. Three of the projects, E-Werk Prad, Ameland and the municipality of Hostetin, meet all RE-cluster criteria without reservation. The other two clusters each meet the complementarity requirement, but are missing only one of the three of bi-directionality, flexibility or interconnectivity. All five projects meet

Table 3
Number of consumer co-ownership projects that meet multiple criteria.

	Meets 1 of 3 criteria	Meets 2 of 3	Meets 3 of 3
Number of projects	16	4	5

Table 4
Projects with RE-Cluster potential not meeting the REC criteria of heterogeneity or governance[a].

Country/Name/year set up	Complementarity: Diversity of RES/ownership	Flexibility/interconnectivity/bi-directionality
Spain: Barcelona Energia, 2017	41 solar PV plants on Barcelona City Council buildings, waste-to-energy plant and biogas plant (total 45 MW); 17 solar PV pergola systems on public squares and parks; supplies municipal buildings and planned ca. 1260 households in 2019/owned by the municipality of Barcelona[c]	Bi-directionality/interconnectivity: municipal incentive program for citizens who want to set up solar PV and solar thermal systems either individually or collectively; installations can be set up entirely for self-consumption or grid connected[cd]. No indication of flexibility measures.
Czech Republic: Kněžice bio-energy centre, 2007	Biogas plant with CHP (output: electrical 330 kW, thermal 405 kW) and a municipal heating plant consisting of two boilers (800 and 400 kW) cover Knezice's heat and electricity demand entirely[e]/owned by the municipality of Knezice.	Bi-directionality/interconnectivity: excess electricity from biogas plant sold to the grid; No indication of flexibility measures.

[a] If not indicated otherwise, the information on the cases is retrieved from the original dataset (see [1]. Source of information: a) [47]. b) [48]. c) [49].

the heterogeneity and governance requirements of RECs and are classified as such.

5. Discussion

With regard to the results of above analysis we, however, would like to remark on the limits of the data set referred to that may have affected the outcome. The list of cases used for the analysis is not exhaustive. More or different cases could have been included but for a variety of reasons were not chosen to be included in the country chapters by their authors and, of course, there may have been gaps in information on the cases reported. Furthermore, the criterion of consumer (co-)ownership used in the sampling frame narrow the perspective to a certain extent; this stems on the one hand from the ownership structure as a determinant of control within the EUs new governance framework and on the other hand from the function of (co-)ownership as an economic incentive. It should be mentioned that alternative ownership settings, however, are possible in energy communities that do not comply with RED II.

The results demonstrate that while elements of RE-clusters are already happening in the current market, there seems, indeed, need for rules to support all of the elements of RE clusters to occur simultaneously. These findings also support our argument that energy clusters and energy communities are mirrors of the same concept. The absence of the governance and heterogeneity criteria is often observed in projects that fall short of cluster elements of flexibility, bi-directionality and interconnectivity (Table 4), while the presence of most of the cluster criteria occurs simultaneous to the governance and heterogeneity criteria being met (Table 6). Projects in Table 5 are somewhere in the middle, requiring slight modifications to all criteria to be considered both RE-clusters and RECs.

What is striking in terms of geography about the five model RE-clusters and the two "nearly clusters" is that they are all sited in rural areas. This may relate to the fact that several RES technologies are only feasible further away from population centres as discussed in section 3.1. Also, the Eigg and Ameland projects are sited on islands whereas the Huatacondo and E-Werk Prad projects are situated in a remote mountain areas. This suggests that in the absence of further facilitating rules for urban areas, isolated and rural communities are a more facilitative setting for the emergence of energy clusters due to the importance placed on self-reliance and resource availability [see also 64]. It raises the question, however, whether rural communities, due to their members living at potentially long distances from each other and the installations, would be eligible as RECs according to the proximity criterion set out in RED II (see discussion in section 3.2). Furthermore,

Table 5
RE-Projects already or nearly functioning as clusters but not fully meeting the REC criteria of heterogeneity or governance[a].

Country/Name/year set up	Heterogeneity	Cluster potential	Governance & Ownership	Still needed to qualify
France: Le Mené's energy self-sufficiency project, 2007	A group of local officials, individuals, mostly farmers organised in local cooperative, partner with installation operators through the association of municipalities Le Mené in rural Brittany	• Complementarity: collective methane production, bio fuel production, 6 MW installed capacity wind farm; • Interconnectivity: Also includes biomass powered heating district[a] • Bi-directionality: wind farm is connected to the main grid • Flexibility missing	• Wind farm owned 30% by local citizens; 50% by energy company Idex and 20% by a public bank; • Methane plant owned in thirds respectively by local farmers cooperative, public bank and energy company Idex; • Bio-fuel production plant owned by local farmers cooperative[a]	• Governance criteria only partly met with large energy firm not based in the area holding majority stake in the wind farm
Chile: Huatacondo micro grid project, 2010	• Situated in remote Andes mountain town of Huatacondo; • Implementation supported by University of Chile and funded by a mining company	• Complementarity and flexibility: Hybrid system of a 23 kW solar PV plant, a 3 kW wind turbine, a 120 kV A diesel group, and a 129 kWh storage system part of a smart grid; • Interconnectivity and bi-directionality: micro grid[b]	• Ownership of installations to be conferred to the Huatacondo community; • Involvement of locals in operating the system through smart technology, basic maintenance activities carried out by locals	• Heterogeneity and governance will depend on transfer of ownership stakes to community; • Latest available information on project confirms installations still owned by the mining firm[c]

[a] If not indicated otherwise, the information on the cases is retrieved from the original dataset (see [15]. Source of information: a) [50]; b) [51]; c) [52].

Table 6
RECs that are model or almost model RE clusters[a].

Country/Name/year set up	Heterogeneity	Cluster potential	Governance & Ownership
Netherlands: Duurzaam Ameland, 2007	Partnership between municipality of Ameland and a number of private and public entities to set up innovative sustainable energy projects on the island.	Projects include: • Solar PV farm (6 MWp) 2010; • Flexibility, bi-directionality and interconnectivity: Development of largest micro grid of the Netherlands in 2019; enabled by an exemption from electricity regulation[a]; • Complementarity: Municipality addresses volatility of solar energy primarily by fuel cells supplied with natural and biogas; supplementary heat pumps and combined-heat-power stations connected to micro-grid[a]	• Solar farm co-founded by municipality, local energy cooperative and Eneco, a large energy company; • Founding partners each hold a third of the shares guaranteeing the autonomy requirement for RECs
Scotland (UK): Isle of Eigg electricity grid, 2008	• Operated and maintained by Eigg Electric Ltd. a 100% subsidiary of Isle of Eigg Heritage Trust, the community organisation owning the island; • Trust's members are Isle of Eigg Resident's Association, Highland Council and Scottish Wildlife Trust; • Financial support of a number of public and private entities for inception[b]	• Complementarity and interconnectivity: Stand-alone or off-grid micro-grid system with hydro-electric, solar PV, and wind power (combined 184 kW); • Flexibility: Bank of batteries; off-grid Feed-in-Tariff covers operating costs; back up diesel power generation[b] • Demand management: 5 KW cap on energy consumption for each household and 10 kW for business premises to cope with volatility of RE; households keep track of consumption levels with individual electricity meters[c]	Majority of appointed local residents on Isle of Eigg Heritage Trust's board[c] ensuring project's compliance with heterogeneity, governance and ownership criteria;
Czech Republic: Hostětín municipal heating plant, 2000/ PV, 2008	Rural village of Hostětín: • Heating plant funding: 54% State funding, 31% Dutch grant, 9% Czech Energy Agency, 6% residents connected to heating plant; • PV plant: joint investment of village and three foundations each holding 31%.	• Complementarity, bi-directionality, flexibility and interconnectivity: Biomass central heating plant fuelled by wood chips (732 kW); solar PV Panels (50 kWp); solar thermal collectors sited both on commercial and residential premises[d]; • Interconnectivity: Solar PV power plant occasionally supplies electricity to heating plant[d]	• Local actors Hostětín village (7%) and Veronika foundation (31%) holding 38% of stakes in heating plant and 62% in PV project thus effectively controlling both; • Biomass plant funded by grants and operated and owned by village[d]
India: Odhanturai 1996	Local government's green energy programme contributed EUR 186,000 to the wind turbine, remaining EUR 48,000 by villagers and EUR 138,000 bank loan taken on by village council of rural Odhanturai.	• Complementarity: 1996 solar street lighting; 2006 a 350 kW wind turbine in village and 9 kW biomass gasifier power generation system to substitute grid electricity for pumping drinking water[e]; • Bi-directionality: Amortized loan by selling part wind turbine's produced electricity to local grid operator; remaining part supplies residents; • Interconnectivity: biogas system is connected to each house for cooking purpose	Installations owned and operated by the village council, minority share held by villagers[e]
Italy: E-Werk Prad, 1926	• Plants and grid owned and operated by a local cooperative of which 1,300 families, local SMEs and municipality are members; • Coop members benefit from discounted energy prices due to exemption from system costs for self-sufficient cooperatives[f]; • Electricity consumption is 64% coop members vs. 36% non-members[g]; • First investment in 1927 in hydro-electric powerplant of 375.000 Italian Lire (equivalent to value of 300 milk cows)[h]; 2001-17 14 mln. EUR investment in district heating, with the region contributing 30%[i].	• 4 biomass stations (total 7.4 MW), 210 solar thermic plants 2,200 m^2, 5 micro hydro plants (4,082 kW) and 141 solar PV installations (total 6.87 MW) cover Prad community's heat and electricity demand entirely[j]; • Bi-directionality/ interconnectivity: Cooperative members can install solar PV panels on their premises and feed electricity into the grid[k].; • Flexibility measures: own local electricity grid and district heating as well as 2 buffer tanks with a thermal storage capacity of 293,000 litres.[g]	• Most local families (ca. 95%) participate, local SMEs and municipality[g]; • One member / one vote principle independent of capital share in project; • However, Italian cooperative law allows privileged position of investing members with regard to voting rights.

[a] If not indicated otherwise, the information on the cases is retrieved from the original dataset (see [15]. Source of information: a) [53]; b) [54]; c) [55]; d) [56]; e) [57]; f) [58]; g) [59]; h) [60]; i) [61] j) [62]; k [63].).

the Ameland, Huatacondo and Le Mené projects required the participation of – at least in the inception phase – a large firm as main or co-investor. Due to lower population density in rural areas there may be fewer potential investors than there are in urban areas, that are typically communities of interest. Projects in these areas may require financial participation of larger firms based outside of the energy community's area. These firms may insist on majority share ownership. However, projects set up under this condition would be disqualified as REC and not eligible to benefit from the RED II "enabling framework". Furthermore, considering the high energy demand in urban areas and ambitious climate and energy targets municipalities around the world have set, they will need increasing RES supply [23,65]. An open question is how to facilitate the proliferation of RECs and RE-clusters in any context and in particular in urban areas. The RED II "enabling framework" focussing on Communities of Place should therefore be kept flexible by the national legislator when spelling out its specific conditions allowing – where appropriate – to include also Communities of Interest as well as and Communities of Interest and Place [13].

The Eigg, Hostetin, Huatacondo and Odhanturai projects for the investment costs relied for a large part on public and private grants. This points to the importance of external funding for the economic feasibility of energy communities. An enabling framework should facilitate this kind of funding for example through tax breaks for donors and investors and/or credit guarantees and access to capital credit at low interest rates.

But even broader support may be needed through a clearly preferential regulation for off-grid and micro-grid projects, as the Ameland, Eigg and E-Werk Prad projects illustrate, and it appears that this should include aspects of technology. In the case of flexibility, for example, in the cases of Eigg and Huatacondo, the active involvement in responsive load and demand response by consumers being part of the micro-grid was incentivized. This stresses the importance of flexibility options that enable energy clusters as addressed in section 3.1. When flexibility, interconnectedness and bi-directionality features were not or only scarcely encountered (see the cases of Knezice and Barcelona in Table 4), there was also a lack of diversity in participating actors in these projects. But even more important to broader support is the issue of complementarity, as this may be related, for example, to a range of actors that could contribute expertise and complementary RES installations. As outlined in Table 2, the cases that meet minimum conditions to be an RE cluster have a variety of RES in the projects. With regard to the model RE clusters in Table 6 observe a broad range of combinations of RES in the portfolio of the selected cases: three micro-grids with wind turbines, solar PV and storage system in the first; solar PV, fuel cells and CHPs in the second; hydro-electric, solar PV and wind power in the third. The Odhanturai model RE cluster features a combination of solar PV, wind turbines, biomass gasifier and a biogas system. This emphasises that, following theory, in practice possible combinations in RE clusters are broad and tailored to local conditions. This circumstance should be taken into account and complementarity with considerations that it can be enhanced by the interconnectivity of multiple distinct actors should be deliberately incentivized when transposing the "enabling framework" of RED II into national law until June 2021.

Ameland and Eigg each tapped into preferential regulation that removed obstacles for their implementation. These "regulatory sandboxes" [66,67] are an indication that the forthcoming preferential conditions contained in the "enabling framework" of RED II will be important for the establishment of RECs. And, indeed, the German Federal Ministry for Economic Affairs and Energy (BMWi) has launched an initiative introducing so called "Regulatory Sandboxes for the Energy Transition" (in German: "Reallabore der Energiewende")[18] More generally the fact that in the majority of the RE-projects with cluster potential governance or heterogeneity requirements of RED II are absent indicates that when RE clusters are structurally present, an enabling framework could effectively encourage local control of projects as well as heterogeneity of their members and such promote the emergence of RE clusters.

6. Conclusions and policy recommendations

It is increasingly argued that social justice principles should be integrated into the development of energy systems [69]. In this light, RED II explicitly underlines the social community benefits of RECs (see definition in Art. 2, pt. 16). The social aspects of such projects like, for example, low-income tenants in buildings with split incentives for prosumership, merit further attention which, however, was beyond the scope of this paper. Overall, our findings indicate that RE clusters and RECs are the socio-technical mirrors of the same concept. Our analysis of a global dataset of consumer (co-)ownership suggests it is not often to have one without the other. In order to ensure success of the regulations, our recommendations are therefore to simultaneously and holistically encourage the implementation of all elements of RECs and RE-clusters. This is particularly important where these are conceptualised as *flexibility options* that entail *interconnectivity* of all sorts of different actors – be they small or large, professional or not – and *bi-directionality* of energy flows, with *complementarity* of different energy sources.

In consideration of the pending transposition of the RED II and IEMD/R into national law, several key questions about energy communities and RE-clusters emerge. One is whether the legislation sufficiently encourages or in places even inadvertently discourages complementarity between RES, a critical factor that affects the technological ability to integrate RES that in turn their economics and in particular their financing. The transposition of the new rules should therefore as much as possible encourage complementarity of a variety of RES. We have concerns that complementarity may not be sufficiently incentivized by the transposition, or may unintentionally be hindered by any rules that impact the spatial organization of RES complementary [5,6,30]. For example, interactions with land-use planning rules need to be carefully considered.

6.1. *The proximity criterion*

Eligibility requirements of proximity of shareholders in the RED II should be analysed for their impact on complementarity in particular in urban settings. The nuances of location require that proximity be not too narrowly defined. For example, a question that arises about the interaction between the location of the elements of RE clusters and governance requirements, is what will be the proximity requirements of shareholders or members to the elements of the RE-cluster? Is it proximity to the specific RES installation/producer/prosumer, to the jointly owned distribution system, or to all of the elements, all installations and distribution, of our definition of a cluster as a whole? The wide interpretation of electricity sharing permitting virtual net metering where a REC owns at least two metering points is a clear indication the European legislator has conceived the proximity criterion in a way that will facilitate RE clusters. However, this should be communicated early and in a clear manner to the 28 Member States to prevent misunderstandings during the transposition process.

Complementarity can also be stimulated by the implementation of heterogeneity requirements, if a range of actors with various resources are encouraged to the system simultaneously. For example, the literature points out that when solar PV and wind power are complementary, this can drive down system costs of flexibility [5] and improve capacity integration [24,32]; therefore, sites that have high potential for complementarity for solar PV and wind should be encouraged to develop both resources simultaneously, be it within a REC or even with different owners, since the overall capacity will increase on the system at lower overall cost. This again is an issue closely related to the interpretation of the RED II proximity criterion when transposing the directive: the siting requirements, both with regard to geographic conditions and to spatial planning regulation may involuntarily hinder the setting up of RECs and the possibility of electricity/energy sharing within them if interpreted too narrowly.

6.2. *Rules for energy sharing*

Complementarity in turn is only enabled with interconnectivity and bi-directionality. Complementarity as heterogeneity of actors and RES could again be helped or hindered in the planning and development stages. Well-tailored incentives will be crucial as to whether complementarity between resources brought to the REC by different prosumers and producers each may improve the economics of the overall RE-cluster. Furthermore, also timing and process of procurement may be important considerations, and whether the RES are considered

[18] Such real-world testing environments are operated for a limited period of time and across a set area and are intended to allow for the testing of new technologies and business models, which are only partially compatible with the existing legal and regulatory framework. The BMWi is funding projects within the timeframe 2019–2022 in an amount of up to 100 millions euros per year; see [68].

individually or holistically and spatially may be a challenge. For example, would a farmer providing wind power be more encouraged in the presence of rooftop solar power production across the buildings of a village on a system? In this case, the implementation of planning methods such as "spatiotemporal modelling of RES" proposed by Ramirez Carmargo and Stoeglehner [6] or "sustainable energy district" for an urban area proposed by Bracco et al. [9] are important considerations for policy makers.

Our findings, and the literature, also point out that *flexibility,* as active network management, storage, and demand response, are key in improving the capacity and economics of these systems, and in the implementation of RE-clusters and RECs simultaneously. For example, in the case of grid connected solar PV and wind complementarity, both active management and curtailment rules impact the RE capacity of the network [24]. Our findings show that four of the five RE clusters and RECs (Table 6) explicitly contained elements of flexibility, however, given that Odanthurai is in a context of limited energy access in India, it is arguable that this system contains more flexibility arrangements as demand response and demand management than most other projects. With the right to demand the installation of smart meters and the introduction of “energy sharing”, the fundament for these cluster elements is laid down in the RED II and IEMD/R. In this context, the new rules for RECs on priority dispatching and curtailment as well as those on ownership and management of distribution networks are to be welcome, and again should be combined with incentives for complementarity. However, it is regrettable that both priority dispatching and exemptions for RES from rules on curtailment are to be successively phased out and the national legislators should take the complexity of the tasks of RECs in RE clusters into consideration when introducing compensatory incentives.

6.3. *“Regulatory sandboxes”*

More generally speaking, against the background of the important benefits of complementarity of RES, *flexibility, interconnectivity* and *bi-directionality* discussed in the theory section, it is surprising that the new legal framework of the RED II and IEMD/R does not focus more on specific incentives encouraging these elements of RE clusters in combination. In particular, RED II, that also covers other forms of energy than just electricity (e.g., similar to multi-energy systems [7] or "autonomous polygeneration microgrids" [8]), should be careful to not unintentionally discourage RE clusters. A lot will depend on the specific national rules of the RED II “enabling framework” for RECs. Here “regulatory sandboxes” as a real-world testing environment, operated for a limited period of time, could allow for the testing of incentives for RECs and the required business models to identify best practise when overcoming obstacles stemming from a lack of compatibility with the existing legal and regulatory frameworks. An example is the concept of Consumer Stock Ownership Plans (CSOPs) that is being implemented in the Horizon 2020 project SCORE[19] [70]. This innovative concept not only enables participation in RECs by previously underrepresented groups, but also provides a business model for RECs that function as RE clusters [71] and merits discussion in a follow-up article. Finally, as the absence of the governance and heterogeneity criteria is often observed in projects that fall short of the RE cluster elements of flexibility, bi-directionality and interconnectivity, the combination of these aspects in the Clean Energy Package of the EU should be considered an important milestone.

[19] SCORE runs from 2019 to 2021 and facilitates consumers to become (co-) owners of RE in three pilot regions and in cities across Europe following these pilot projects. Vulnerable groups affected by fuel poverty – as a rule excluded from RE investments – are in the focus of the project.

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