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Typology of future clean energy communities: An exploratory structure, opportunities, and challenges

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ABSTRACT

This paper considers the potential significance of 'clean energy communities' (CECs) in the transformation of the present socio-technical regimes underlying our centralized energy systems, towards a more distributed and decentralized future. It explains the centralized, distributed, and decentralized sub-structures, embedded in current energy systems and energy markets. We analyze long-term dynamics and possible pathways of this transition, and the co-evolution of energy systems and communities, using an exploratory structure, drawing on insights from transition theories, innovation studies, and social network concepts. This includes analysis of the various forms of CECs – including virtual power plants, peer-to-peer trading, microgrids, and community-scale energy projects – emerging in a number of developed and developing jurisdictions, including Australia. This analysis suggests that low-carbon transition pathways will be varied, driven by social, technological, and organizational contexts, and shaped by institutional change processes, and interaction with the existing regime and incumbent actors. Social and technological entrepreneurs, and utilities, operating within an environment increasingly defined by energy consumers, industry groups, and policy actors, will need to be adaptable and innovative in choosing strategic directions, associated investment decisions, establishing appropriate alliances, and acquiring resources, to meet their goals in this low-carbon energy transition.

1. Introduction

Electricity industries around the world have evolved over the past century towards typically large-scale generation facilities and centralized transmission and distribution (T & D) networks, owned and operated by large investor-owned or state-owned businesses. This was largely an outcome of social objectives of universal energy access given the industry's key contribution towards societal welfare and economic progress, economies of scale with large conventional generation and networks, yet the challenges this raised for accessing capital and operating large interconnected power systems [1]. However, the rapid development and uptake of renewable technologies and distributed energy over recent decades, facilitated by supportive technological and social innovations, as well as growing government efforts with climate change initiatives and policies to promote clean energy, is now rapidly altering the electricity industry landscape worldwide.

In the coming decade, it is widely expected that distributed energy resources (DER) capacity additions in the form of physical infrastructure, such as solar PV, generator sets, controllable energy storage, and electric vehicles will play an ever greater role. Navigant Research [2] estimates the ratio of DER capacity deployment compared to new centralized generation might reach 5:1 by 2024, and that annual revenue for the global residential DER market alone is expected to increase from approximately US$20 billion in 2016 to US$93 billion in 2025. As another example, Jacobson's study of least cost 100% renewable energy systems for 139 nations suggested some 28% of all-purpose annually averaged end-use energy demand might be met by rooftop PV, comprising 1.8 billion 5-kW residential rooftop PV systems (14.9%) and 75 million 100-kW commercial/government rooftop systems (11.6%) [3]. While no one knows what the future will hold, and there are certainly centralized utility technology pathways to a low carbon energy future, it seems likely that small-scale DERs will play a key role. Hence, questions of how widespread DER deployment might be facilitated, are important considerations for policy makers grappling with our energy challenges. It is interesting to note that a number of jurisdictions that have set amongst the most ambitious low carbon targets such as Denmark and Germany, have formally recognized that the transition to a renewable energy future requires incorporating energy systems that are tailor-made at the local level as well as centralized power production, and hence the strategic role of municipalities, local stakeholders, and

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authorities to formulate such initiatives [4,5].

The sheer scale and complexity of incorporating millions and even billions of DERs into current energy systems, calls for joint, coherent, and comprehensive efforts by all stakeholders including policy makers, utilities, as well as consumers and communities. It also brings new players into electricity industry decision making, and is now prompting the reconfiguration of participant roles and functions in the energy supply chain. In particular, the industry's traditional centralized electricity supply structure and utility-dominated decision-making regime is being challenged by energy users. Households and communities, are no longer confined to participating only as passive consumers of electricity services, but are increasingly involved as producers/prosumers, investors, and asset owners, making key investment decisions for themselves individually, or collectively as 'clean energy communities' – the focus of this paper. In this paper, the term 'prosumers' refers to "an energy user who generates renewable energy in its domestic environment and either stores the surplus energy for future use or vends to the interested energy buyers" [6]. We acknowledge, however, that the concept is often extended to include 'professional' consumers who are actively engaged in the provision of their desired energy services beyond just renewable energy generation. The emergence of clean energy communities (CECs) reflects the individual community energy needs, their desires and engagements in addressing social, environmental, and economic opportunities and challenges in local energy production and use, often in response to regulatory incentives, inadequacy of tailored electricity products/services, or deficiencies in the current electricity markets they reside in. Secure and efficient operation of the electricity industry requires high levels of cooperation and some key industry costs and benefits depend on aggregated outcomes. Individual consumers are limited in many regards in terms of meaningful engagement by existing regulatory arrangements and market incentives in the current electricity markets they reside in [7]. Despite many challenges, successful examples of community level engagement and community projects can be sought, even in some most impoverished and isolated communities with meagre resources when appropriately facilitated [8,9]. This means that the pathways to a low-carbon energy future will not only be influenced by the technological development and centralized decision-making that shapes so much of present discussions, but also by decentralized social institutions and practices, which currently lie outside traditional governance and decision making.

In this paper, we aim to provide insight into how some clean energy communities (CECs) are emerging within the electricity sector, the opportunities and challenges they pose for current market and regulatory arrangements, and how they might be further facilitated. We first consider different drivers, and possible forms of CECs, including discussion of diverse configurations of different community energy initiatives in Australia to date, including community-scale energy projects, net-zero emission townships, virtual power plants, peer-to-peer trading, community microgrids, and integrated community energy systems. A key reflection is the inadequacy of existing frameworks for recognizing the potential and future role of CECs in a more structured way that can assist in facilitating better understanding and progress towards a low-carbon energy transition. We then present three typologies of future clean energy communities- centralized, distributed, and decentralized CECs- by employing an exploratory structure drawn from innovation studies and social network perspectives, taking into consideration the different goals and motivations of communities, and impacts from broader energy markets and policy frameworks. Finally, we use transition theory insights, particularly around organizational and institutional perspectives, to examine how CECs in the Australian context to date have co-evolved with the various dimensions of the energy system, such as regulations and institutions, environmental initiatives, market structures, technologies, and business models. Our study is intended as a step towards developing an understanding of the potential opportunities and dynamics of greater community involvement in future energy systems, based on different interdependencies and interactions among different actors, such as utilities, regulators, technology innovators, communities, and consumers. The Australian context includes naturally abundant solar and wind resources, a geographically expansive yet aging electricity network infrastructure that includes extensive regional and rural lines serving small remote communities, and a set of market and regulatory arrangements that offer limited interfaces for consumer participation [7]. Still, the findings have broader relevance to CEC developments in other jurisdictions given that electricity industries around the world are, to varying degrees, also grappling with these questions.

2. Definitions and drivers of clean energy communities

2.1. Definitions of clean energy communities

"Energy communities", should not be confused with 'community energy' that has been studied extensively in the literature [10–13]. Despite this effort, there does not yet seem to be a consensus on the definition of 'community energy' – what types of arrangements count as community energy, and what role communities should play in a community energy setting. Some researchers emphasize the involvement of community ownership [14], while others classify 'community energy' based on the outcomes and the process for developing the project [15], including the level of benefits that flow to the hosting community, and the form and depth of community involvement in design and implementation. Even though energy cooperatives for clean energy supply, such as wind, biomass, and solar are the most popular form of community energy to date, some community energy projects are also established to encourage demand reduction, facilitate tariff negotiation, behavior change, or some mix of these [16]. Despite the lack of consensus on what precisely it includes, community energy is seen by many researchers as a major force and at the center of the social movements in tackling future energy and climate change challenges.

Compared to 'community energy', 'energy communities' has emerged as a related concept which in our view more specifically defines the relationship of communities with their intended energy management. Schweizer-Ries (2011) argued that energy sustainable communities should be defined according to their involvement in the process of energy sustainability, rather than from the technical perspective only, as 'communities that covers more than 50% of their total energy demand from renewable energies' [17,18]. Dóci et al. introduced renewable energy communities (RECs) as a special type of grassroots initiative that produce or invest in the production of renewable energy to cover their own energy needs. As social niches, they can be adopted by parts of the regime when new business opportunities are created and local problems are solved [19]. Romero-Rubio and de Andrés Díaz consider 'Sustainable energy communities (SECs)' as organizations whose members are strongly involved in the planning and implementation of measures aimed at the rational use of energy and introduction of renewable energy sources (RES) in the production, consumption, and/or supply of electricity, that have contributed to the development of renewable energy infrastructure [20]. Van der Schoor et al. suggests that energy communities that promote local sustainable energy production, can form new connections and new type of energy providers, interacting with local, regional, and national networks, to provide social innovations in a decentralized energy system [13].

In this paper, we expand the concept of 'clean energy communities' (CECs) to a broader scope, emphasizing their functional and goal-oriented properties to meet the needs of individual community. We define them as '*social and organizational structures formed to achieve specific goals of its members primarily in the cleaner energy production, consumption, supply, and distribution, although this may also extend to water, waste, transportation, and other local resources*'. Based on how these CECs interact with the existing centralized energy systems and regime, we have categorized different forms of CECs into three types, namely centralized, distributed, and decentralized CECs. These categories are