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Renewable micro-generation of heat and electricity—Review on common and missing socio-technical configurations

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ABSTRACT

A widespread adoption of distributed generation (DG) technologies in energy systems can play a key role in creating clean, reliable energy and support the targets of emission reduction. A transition from current modes of production to a significant deployment of renewable energy technologies can fundamentally affect the structure of the industry and change the way energy is produced, transmitted and sold. The current paper provides an extended review of the socio-technical configurations of micro-generation based on journal publications and reports during the 21st century. The paper analyses currently existing and missing configurations and discusses technology and policy implications to support proliferation of micro-generation technology and local energy production from renewable sources. The potential for new configurations can be found particularly in heat producing micro-generation with solar heat, heat pumps, and biomass. Developing further the operations and maintenance of distributed generation technologies and business models appears an area that calls for further innovation, and corresponding innovation policy measures. Third party service and community-driven deployment models can aide the proliferation of distributed generation and further innovation therein, justifying the introduction of feed-in-tariffs to attract such models during their early diffusion.

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Contents

1. Introduction . . . 2
   1.1. Concept of micro-generation . . . 2
2. Analytical framework . . . 3
   2.1. Organizing around micro-generation . . . 3
   2.2. Methodology and procedure . . . 3
3. Existing configurations—Technical and non-technical aspects . . . 4
   3.1. Technologies of micro-generation . . . 4
   3.2. Ownership and financing . . . 4
   3.3. Operation and management . . . 5
   3.4. Distribution of energy . . . 7
   3.5. Summary on existing socio-technical configurations . . . 9
4. Missing socio-technical configurations . . . 10
   4.1. Technological limitations . . . 10
   4.2. Service-based models and limited market demand . . . 11
   4.3. Opportunities with community energy . . . 11
5. Policy implications of missing configurations . . . 11

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6. Conclusions . . . 12
Acknowledgements . . . 13
References . . . 13

1. Introduction

Decentralized energy production based on renewable sources is a commonly presented vision and solution for future energy needs [1]. The exponential growth in distributed photovoltaic installations has been accompanied with a widening range of their deployment models. Other decentralized renewables appear to feature fewer alternatives to the deployment models. As a fuller range of available models could also help the proliferation of these technologies, it is worth examining whether these technologies have hitherto been deployed in a more limited array of models, and if so, are these limitations inherent or could they be subjected to targeted measures for innovation and for energy policy. After an analytic review it appears that only some of the limitations are inherent and there is room for development.

According to recent research, distributed generation (DG) technologies may yield significant benefits in terms of energy efficiency and reduced carbon emission. This is due to the fact that DG combines geographically dispersed decentralized generation from preferably renewable sources [1,2]. DG can reduce losses in energy distribution [3], improve energy security by producing energy close to the point of consumption [4], facilitate an increase of energy services in remote rural areas in developing countries [5–9] and consequently it may foster social equity by providing energy services and capacity for households and villages to reduce extreme poverty and advance standards of living [10]. In addition, DG from local renewable sources, also called micro-generation, can reduce dependencies on foreign energy sources.

Energy technologies are not just material objects, they also can be seen as embedded components of socio-technical systems—in which energy final users, producers, infrastructures, regulators, and other intermediaries are all embroiled [11–14]. A transition from current modes of production to significant deployment of renewable energy technologies will fundamentally affect the structure of the energy industry and change the way that energy is produced, transmitted, and sold [15–19].

Technologies emerge through active development, linkages, and the alignment of various heterogeneous, social, and technical elements into working configurations [20]. Science and technology studies (STS) have revealed a wide variety of different “configurations” of renewable energy technologies and the elements of social organization involved in their deployment. Socio-technical configurations comprise assemblies of technological components, and non-technological components such as human factors. A configuration can be seen as an unique assembly of components built up to meet the particular requirements of organization [21,22]. These organizational interacting mechanisms around energy technology include dimensions such as ownership, management, operation, and infrastructure [11].

Another stream of literature and research has been interested in value chain(s) in the renewable energy business and deployment models [4]. Especially the issue of utilities’ business models for renewable energy has been addressed by a number of recent reports [18,23–26] and academic studies [27].

Both streams of literature show how organizing a micro-generation is in constant change and new configurations are emerging. Production of renewable energy is becoming multi-faceted and clear demarcation lines between centralized and decentralized, grid-connected and off-grid, and producer and consumer, are increasingly becoming blurred. New configurations consist of different sizes of networks that underpin the energy consumption of consumers and communities [2].

This paper is interested in the deployment of micro-generation technologies. The article departs from the framework introduced by Walker and Cass [11] in 2007, and adapts it to discuss renewable micro-generation, the covering technologies, ownership, financing, production, and the distribution of energy. Our contribution is twofold. First, we review current academic literature complemented with up to date documents to reveal existing socio-technical configurations of renewable micro-generation technologies. Second, we analyze technological and organizational combinations that create configurations which remain unrealized or marginalized cf. [28]. Our findings offer insight for policy makers in the field of energy, and help companies and user groups to understand various opportunities and current restrictions when enhancing the diffusion of micro-generation technologies and scaling up local renewable energy production. Such insight and opportunities have been hitherto discussed mostly with regard to the solar photovoltaics (PV) domain only, and we expand on this.

The article begins with opening up the concept of decentralized generation, micro-generation, and the methodological approach that will be used in this study. We then describe different types of socio-technical configurations taking place in the micro-generation of heat and electricity. In Section 4 we analyze marginal and missing configurations and the reasons that hinder the emergence of certain configurations. Finally, we discuss innovation and energy policy implications and how these could speed up the proliferation of micro-generation technologies.

1.1. Concept of micro-generation

Decentralized or distributed energy supply refers to the generation of energy close to the place where energy is used. It can mean a range of generator sizes; from residential households to community or district-level [3]. Micro-generation is the term given to small-scale local energy generation, and it has various definitions, which vary from country to country. The key characteristics of these definitions are that micro-generation occurs at a local scale, it can include both the generation of heat or electricity or both, and it generates small amounts of energy compared to centralized plants. Furthermore, there is often a requirement of environmental friendliness in the production. For example in the UK, the Energy Act section 82 defines micro-generation as generating plant with a capacity of less than 50 kW. Most residential installations are in the range of 2.5–3 kWpcs [3,27]. In the case of electricity, it can be for the sole use of the building’s occupants or it can feed the National Grid.

Various renewable energy sources are used for micro-generation. These include solar, wind, biomass power (e.g. wood, wood pellet, bio waste), and the utilization of outdoor and ground source heat. Hydropower can also be built on a small-scale, the capacity defined as small, mini or micro-hydropower [29]. It is noteworthy that micro-hydropower definitions of size and capacity differ from other sources, and a hydropower plant with the capacity of between 50 kW and 10 MW is still considered as a micro-hydropower [30,31]. Definitions of small-scale Waste to Energy (WTE) systems have some variations. There are studies [32,33] that define small-scale WTE is as capacity

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