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Wolsink, M.

DOI
10.1080/01426397.2017.1358360

Publication date
2018

Document Version
Final published version

Published in
Landscape Research

Landscape Research

ISSN: 0142-6397 (Print) 1469-9710 (Online) Journal homepage: http://www.tandfonline.com/loi/clar20

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To cite this article: Maarten Wolsink (2018) Co-production in distributed generation: renewable energy and creating space for fitting infrastructure within landscapes, Landscape Research, 43:4, 542-561, DOI: 10.1080/01426397.2017.1358360

To link to this article: https://doi.org/10.1080/01426397.2017.1358360

Published online: 25 Sep 2017.

LANDSCAPE RESEARCH, 2018
VOL. 43, NO. 4, 542–561
https://doi.org/10.1080/01426397.2017.1358360

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Co-production in distributed generation: renewable energy and creating space for fitting infrastructure within landscapes

Maarten Wolsink

Department of Geography, Planning and International Development Studies, University of Amsterdam, Amsterdam, The Netherlands

ABSTRACT
This review describes the infrastructural elements of the socio-technical system of power supply based on renewables and the role of landscape concerns in decision-making about emerging 'intelligent grids'. The considerable land areas required for energy infrastructure call for sizable 'distributed generation' close to energy consumption. Securing community acceptance of renewables' infrastructure, perceived impacts on the community, and 'landscape justice' requires two types of co-production: in power supply and in making space available. With co-production, landscape issues are prominent, for some options dominant. However, 'objectification' of landscape, such as the use of 'visibility' as proxy for 'visual impact', is part of lingering centralised and hierarchical approaches to the deployment of renewables. Institutional tendencies of centralisation and hierarchy, in power supply management as well as in siting, should be replaced by co-production, as follows from common pool resources theory. Co-production is the key to respecting landscape values, furthering justice, and achieving community acceptance.

KEYWORDS
Distributed generation; co-production; visual impact; common pool resource; intelligent grid

1. Introduction

To secure social acceptance of renewable energy, communities and stakeholders need to be engaged in two essential 'co-productions': the generation of electricity and the decision-making on establishing the infrastructure for a low-carbon power supply. The latter includes the crucial question of how to create space for all infrastructure related to renewables. Decision-making on the spatial implications of emerging renewable energy systems (RES) is largely about landscape issues.

In this review, the participation in decision-making about how to create space for renewable energy infrastructure is considered 'co-production'. Developed by Parks et al. (1981), the idea of 'co-production of public services' has become a cornerstone in the polycentric management of common pool resources (Ostrom, 2010), and indeed is relevant for the deployment of renewable energy, which concerns the utilisation of a public service based on common natural resources.

Both dimensions of co-production in establishing new power supply systems are largely determined by the characteristics of communities and the infrastructures (Walker, Devine-Wright, Hunter, High,

CONTACT Maarten Wolsink M.P.Wolsink@uva.nl
The underlying research materials for this article can be accessed at <https://www.researchgate.net/publication/312147351_Co-production_in_distributed_generation_Renewable_energy_and_creating_space_for_fitting_infrastructure_within_landscapes_-_Appendix>

& Evans, 2010). Equally important for the acceptance of these systems by all relevant societal actors are the attributes associated with the specific landscape, which directly shapes the character of the communities. This review systematically discusses the essential conditions for inclusion of stakeholders in the co-production of power supply systems based on low-carbon and renewable energy sources, by focusing on the spatial consequences of RES, primarily landscape values.

The scarce literature reviews that cover the emergence of intelligent grids—the technology that integrates different types of renewable power generation, storage and transmission—have largely avoided the issue of social acceptance (Wüstenhagen, Wolsink, & Bürer, 2007) and the essential landscape question. Our effort seeks to examine the following research question: *Where and under which conditions do landscape issues play a crucial role in decision-making on establishing infrastructure for primarily renewables energy generation?* The result can be read as a research agenda because most conditions as well as landscape issues still need extensive investigation.

First, an inventory is made of the academic literature outlining the characteristics of a power supply system based on integration of renewables. This is not yet a landscape question, although the first dimension of co-production already comes to the fore as 'distributed generation' (DG) (Ackermann, Andersson, & Söder, 2001). In Sections 2–4, the focus on DG is explained, followed by a review of the literature on the relevant landscape issues related to this future power supply system (Sections 5.1–7). The conclusion may be considered as key research issues for the renewable energy and landscape agenda.

2. The characteristics of renewables' deployment

From the 1980s onwards, two major developments are unfolding and increasing the relevance of landscape for electricity supply and demand:

(1) the splintering of central power grids and the simultaneous evolution of regional, decentralised configurations; and
(2) the growing socio-political pressure on fossil fuel and nuclear power generation due to pollution, resources depletion, and climate change.

Traditional power plants are large centralised units, primarily fuelled by coal and oil, more recently also by natural gas, nuclear fission and large hydro-power stations. The current trend is to shift power generation towards much smaller energy conversion units, partly combined heat and power systems, using combustion of carbon-based fuels, and renewable sources without combustion (Bakke, 2016; Lund, 2014). As these units require many additional and also much more diverse physical areas for siting, local landscape variations play a crucial role in decision-making. Primarily landscape is important for selecting the physical options for siting, but it is equally prominent in the assessment of landscape values affected by the infrastructure.

This review focuses on this emerging type of electricity generation capacity. DG is based on a network of multiple, smaller generating units and other infrastructure, situated close to energy consumers. It could be the future perspective of our power supply system (Bakke, 2016). This recognition is important, because as Bakke observes, when it comes to deeply institutionalised systems, like power supply (see Section 4), we often neglect urgent maintenance and delay critical upgrades. These upgrades particularly concern the emergence of DGRS (DG renewable systems) and the adjacent consequences for the organisation of power supply. By contrast, government policies tend to focus on—and prioritise—large, centralised generation systems (CGRS), like offshore wind farms or solar plants. These types of options rely on high subsidies and require strong government support, like radical spatial interventions with hierarchic perseverance (see Section 4). This review focuses on DGRS (Table 1) and intermediate infrastructures (Table 2). The growth of renewables required to meet climate change mitigation goals will depend strongly on DGRS because full coverage of demand by renewables can only be achieved if all the required scarce space for all infrastructure related to renewables becomes available.

The challenge to setting up a reliable and stable system is how to integrate numerous units that generate variable patterns of electricity, according to changing natural conditions (Haidar, Muttaq, & Sutanto, 2015); and how to integrate the electricity supply with patterns of demand that predominantly

Table 1. Distributed generation, options for co-production, spatial claims and landscape-issues.

Type of infrastructure	Size (capacity)	Relevance for co-production/ participation	Spatial claims (amount/type)	Landscape *relevance*/type
Combustion turbine CHP (pref. biomass/biofuel)	1–250 MW	Single owner/co-operative/or central	*Small*/Spot	*Low* Visual impact; Ecology crop cult
Micro-CHP (combustion; pref. biofuel)	35 kW–1 MW	Single owner/co-operative/	*Moderate*/Spots; Larger numbers	*Low* Visual impact; Ecology crop cult
Biomass, e.g. gasification	100 kW–20 MW	Co-operative/Possibly single owner	*Large* (crops)/Areas for growing crops	*High* Ecology crop cultivation
Stirling engine (micro CHP; pref. biofuel)	2–10 kW	Single owner	*None*	*None* Ecology: fuel
Small hydro	1–100 MW	Possibly co-operative/shareholders	*Substantial* basin	*Substantial* Ecology river
Micro hydro	25 kW–1 MW	Co-operative/Single owner	*Small*	*Low* Ecology stream
Wind farm onshore/near shore	5–500 MW	Possibly co-operative/shareholder	*Moderate*/Area combined use	*High* Visual impact/
Off-shore wind farm	20–1000 MW	Possibly co-operative/shareholder	*Huge*/Wide area sailing prohibited	*High*/Ecology/possibly positive
PV panels, crystalline/silicone based	20 Watt–10 kW	Single owner/co-operative	*Moderate*/Large numbers; Combined use	*Moderate*/Visual impact/Ecology when sited on soil
PV arrays/silicone or perovskite based	20 kW–100 kW	Single owner/co-operative	*Moderate*/Large numbers; Combined	*Moderate*/Visual impact/Ecology when sited on soil
PV plants/panels based/ground based	1–500 MW	Central; possibly co-operative or shareholder	*Large*/Large areas; hard to combine	*High*/Visual impact/Ecology soil
Solar central thermal receiver (mirror based)	1–10 MW	Central; possibly co-operative or shareholders	*Large*/Large area; hard to combine	*Substantial*/Visual impact/Ecology: soil
Fuel cells, phosacid/molten/etc. (also Table 2)	200 kW–5 MW	Single owner/co-operative/ shareholder	*Small* Spot	*Low*/Visual impact
Fuel cells, proton exchange (also Table 2: H_2)	1 kW–250 kW	Single owner/co-operative	*Small* Spot; indoor	*None*
Geothermal	5–100 MW	Single owner/co-operative/ shareholder	*Moderate* Spot; track (pipe)	*Low*/Visual impact
Marine energy:				
Waves	500 kW–50 MW	Co-operative/shareholder	*Moderate* Island; coastal	*Moderate* Ecology shallows
Tidal flows	200 kW–250 MW	Co-operative/shareholder	*Moderate* Estuary/bay	*Substantial* Ecology estuaries
Wind turbine off-shore/near shore	200 Watt–5 MW	Private and/or co-operative / shareholder	*Small*; combined with agriculture	*Substantial* Visual impact/Ecology: birds, bats
Saline fresh water gradient: Reverse Electr. Dialysis	100 kW–5 MW	Co-operative/shareholder	*Moderate* Mainly estuary	*Substantial* Ecology estuaries
Saline gradient: Osmotic Pressure	4 kW–50 MW	Co-operative/shareholder	*Moderate* Mainly estuary	*Substantial* Ecology estuaries
Seawater cooling (saving power for Airco)	4 MW–50 MW	Co-operative/shareholder	*Moderate* Coastal/Islands	*Low* Deep coastal water
Ocean Thermal Energy conversion	50 kW-50 MW	Co-operative/shareholder	*Small* Islands	*Low* Ecology

Sources: For constructing tables 1 and 2 many references have been used. All these are available on ResearchGate: https://www.researchgate.net/publication/312147351_Co-production_in_distributed_generation_Renewable_energy_and_creating_space_for_fitting_infrastructure_within_landscapes_-_Appendix.

Table 2. Spatial claims, options for co-production and issues of landscape values of other intelligent grid infrastructures.

Type of infrastructure	Size (capacity)	Relevance for co-production and participation	Spatial claims (amount/type)	Landscape *relevance*/type
Distributed storage				
Heat storage (electric boilers)	1–4 kW	Single owner	*None* indoor	*None*
Heat stored buildings (solar, electric heat pumps)	10–500 kW	Single owner/co-operative	*Low* Resource rights passive solar	*Low* Orientation sun, planning design
'Cold' storage (cooling systems)	1–100 kW	Single owner	*None* Indoor	*None*
Battery storage	500 kW–5 MW	Single owner/ co-operative	*Small* Indoor or spot	*Low* Visual *moderate* waste
Electrolizer/ Fuel cellhydrogen storage	50–1 kW	Single owner	*Small* Indoor or spot	*None*
Electric vehicles (Vehicle-to-grid)	10–100 kW	Single owner/private cars/co-owned	*Very small* Recharging points possible indoor	*None*
Electric vehicles public transport; freight	10–100 kW	Public/private/co-operative	*Small* Recharging points possible indoor	*None*
Storage renewable energy in non heat consumption				
Neighbourhood water systems	10 kW–1000 kW	Co-operative/public/shareholder	*Moderate* Level in basins/groundwater level	*Low* ecology groundwater
Pumped hydro (high altitude water basins)	1 MW–1000 MW	Centralised	*Large* Land use change as with large hydro	*High* Ecology; abandon functions like Agriculture
Desalinisation: reservoirs	10 kW–50 MW	Co-operative/shareholder/public	*Moderate* plant; basin	*Low* visual
Transmission of RES generated power				
HVAC transmission	10–150 kV	Public/private/centralised	*Large* Track in open air	*High* Ecology; Visual impact
Super conducting HVDC transmission	100–1000 kV	Public/private/shareholder	*Small* Narrow track underground	*Low* Ecology underground
Low voltage grid (DC)	20–100 V	Co-operative/household	*Small* Indoor/Underground	*None*
Low voltage grid (AC)	220 V–25 kV	Public/co-operative	*Small* Indoor/Underground	*Low* Visual in case of in open air

Sources: For constructing tables 1 and 2 many references have been used. All these are available on ResearchGate: https://www.researchgate.net/publication/312147351_Co-production_in_distributed_generation_Renewable_energy_and_creating_space_for_fitting_infrastructure_within_landscapes_-_Appendix.

follow socio-economic conditions. The proposed answer is the 'intelligent grid' (Charles, 2009; Coll-Mayor, 2007; Section 3.3), usually known under the buzz-word 'smart grid' (Marris, 2008; Ruiz-Romero, Colmenar-Santos, Mur-Perez, & Lopez-Rey, 2014). Scaling up to intelligent grids with a large number of DGRS units will require new organisational principles and structural changes (Adil & Ko, 2016; Wolsink, 2012), for example, institutional changes in spatial planning (Section 5).

3. Distributed generation

3.1. What is DG?

Dondi, Bayoumi, Haederli, Julian, and Suter (2002) defined DG as

- small capacity units for electricity generation or storage;
- not part of a centralised power system;
- located close to demand.

Remarkably, these are not technical considerations. Similarly, Ackermann et al. (2001) emphasised the unique characteristics of the DG power supply, defining it as

- an electric power source;
- directly connected to the distribution network;
- and at the customer side of the meter.

At first glance, both definitions seem 'objective' in terms of merely noting where the connections to the grid and the meter are located. These are usually considered 'natural choices', the best place according to common sense norms. However, along with many other elements of the current power supply systems, grid connection and metering are institutions, defined in legislation. They reflect past normative and standardised socio-political choices—'path dependency' (Geels, 2004)—that eventually contribute to the institutional 'carbon lock-in' (Unruh, 2000), inhibiting the transition to a low-carbon intelligent grid.

DGRS is challenging the socio-political standards of the centralised power supply (Bakke, 2016; Dondi et al., 2002). The most environmentally friendly DG options are based on non-carbon renewables like solar photovoltaic panels (PV), which directly convert solar radiation into DC (direct current) electricity. DC can be used directly in microgrids (Justo, Mwasilu, Lee, & Jung, 2013), whereas PV interfacing with the grid requires inverters to change DC into 220 V AC, with energy losses. The current 220 V AC system is a significant part of the socio-political path dependency of power systems (Unruh, 2000). In Section 4, we contrast the essential characteristics of DGRS and centralised systems, to understand the implications on spatial implementation and landscape values.

3.2. DG infrastructure and landscape issues

In Table 1 numerous options for DGRS are listed, including contrasting examples of CGRS, such as offshore wind and large PV plants. Most options tend towards geographical dispersion, smaller scales, and a plurality of modes of ownership and operation. Currently, the most widespread DG technology still is the diesel generator, a convenient standalone solution that can be started up and shut down almost immediately (Paliwal, Patidar, & Nema, 2014). Moreover, several other simple micro-turbine devices use biogas and natural gas as fuels (Ismail, Ng, Gan, & Lucchini, 2013) but the environment and health impacts of these micro-turbines remain an issue: they produce locally harmful emissions (NO_x) and rely on carbon-based fuels. While DGRS can have ecological impacts as well, our prime focus is on its implications on land use and landscape values. The most relevant RS options are outlined in Table 1.

PV panels are composed of solar cells, which convert a free and abundant source of energy into electric power. Production costs of panels are continually decreasing and efficiency is continually increasing, due to economies of scale and alternative technologies (e.g. replacing silicone-based crystalline cells with perovskite crystalline structures) (Sum & Mathews, 2014). Continuous innovations are driving the expansion of PV (Toledo, Oliveira Filho, & Diniz, 2010), making it cost-competitive with current prices of electricity delivered through the grid at many places ('grid parity'; Breyer & Gerlach, 2013).

Wind turbines produce source emission-free electricity. Onshore and offshore wind farms should be distinguished as different systems. Onshore wind farms deliver cost-effective results more easily, and 'grid parity' already exists, depending on site, institutional market conditions and proper management (Leary & Esteban, 2009). Offshore wind farms should be seen as CGRS in electricity companies' portfolios, still depending on government interventions like high subsidies. This review focuses on DGRS because rapid growth of renewables to meet the challenge of climate change mitigation depends on independent renewables that are self-sufficient.

Among the other DGRS options (Table 1), fuel cells can convert chemical energy directly into electric power (DC) without combustion, using methanol, methane or hydrogen. Depending how the hydrogen is produced, it could provide a zero-carbon option. Another non-solar option is geothermal energy, with the most obvious application of heating, but with integrating electricity and network of heat (Ajmone-Marsan et al., 2012) or cooling (Lilley, Konan, & Lerner, 2015) geo- or ocean-thermal may also become significant DGRS.

Traditionally, hydro power was integrated in centralised grid systems. Despite being the most widely applied renewable source to date, it is typically a CGRS with heavy landscape impacts, especially ecosystem damage (Tabi & Wüstenhagen, 2017). Increasingly, small and micro-hydro units are providing a DGRS alternative with reduced ecological impact, under the condition of careful siting that takes ecological and landscape concerns into account (Armstrong & Bulkeley, 2014).

Several technologies are emerging for sourcing marine energy (Pelc & Fujita, 2002). Contrary to common sense, (Haggett, 2008) capitalising on their potential is also heavily dependent on acceptance (Bonar, Bryden, & Borthwick, 2015; Firestone, Kempton, & Krueger, 2011), as many require nearshore siting, for example, tidal streams, wave energy, saline gradient, and nearshore wind power (Bedard, Jacobson, Previsic, Musial, & Varley, 2010). Nearshore options can be applied within a framework of DG to serve coastal communities (Alexander, Wilding, & Heymans, 2013). Marine energy systems should also be designed and constructed with careful consideration of seascapes; local biodiversity might even improve the wider marine environment in cases where other ecologically destructive practices are curtailed, like soil disrupting fisheries (Inger et al., 2009).

3.3. DGRS in intelligent grids

The details behind setting up the infrastructure and integrating the diverse power supply and transmission units are the key issues in the emerging new power supply system. The electricity generation of DGRS units is dictated by a combination of meteorological and geographical conditions. As these patterns do not follow energy demand, the challenge is finding a way to coordinate generation and consumption. This is the role of the intelligent grid, defined as a 'power grid consisting of a *network of integrated micro-grids* that can monitor and heal itself' (Marris, 2008, p. 570). Within these microgrids, the generation and consumption of electricity should be integrated 'intelligently', reducing the distance between generation and consumption as much as possible (Karabiber, Keles, Kaygusuz, & Alagoz, 2013). Intelligent microgrids based on DGRS should ideally accomplish the following:

- Integrate different patterns of variable supply of RES units;
- Integrate supply and demand, requiring adaptation of consumption patterns to power generated in the microgrid;
- Integrate several 'prosumers'—consumers involved in co-production of power—in 'microgrid-communities' (Adil & Ko, 2016; Justo et al., 2013; Wolsink, 2012);
- Deploy intelligent meters to monitor consumption and supply from different sources;
- Implement real-time control over energy demand and energy flows within the microgrid, enabled by intelligent meters (Palensky & Dietrich, 2011);
- All enhancing the feasibility of DGRS, including local storage (Siano, 2014).

The location of the meters in DGRS microgrids is not self-evident, especially with the changing institutional framework of power supply systems. Currently the meter is part of 'path dependent' characteristics, such as centralised tariffs and billing (Houthakker, 1951). Intelligent meters are a combination of sensors, monitoring devices, processors, and demand regulators (Marris, 2008)—socio-technical devices that act as hubs for information flows (Jarventausta, Repo, Rautiainen, & Partanen, 2010). In intelligent microgrids they monitor and control energy demand and supply from various DGRS units, taking into account distributed storage, the load patterns of all equipment, and the meteorological conditions for power production.

The meters do not affect landscape values directly, but they further the adaptation of supply and demand patterns that are associated with infrastructure facilities that do have significant landscape impacts. As DGRS means generation of power close to load centres, an intelligent balance between production and consumption would reduce the need to transmit bulk power from large centralised power plants. Hence, DGRS may reduce the stress on electricity transmission systems (Lopes, Hatziargyriou, Mutale, Djapic, & Jenkins, 2007). Transmission lines (Table 2) are infrastructures with problematic acceptance and potentially high landscape impact (Aas, Devine-Wright, Tangeland, Batel, & Ruud, 2014; Komendantova & Battaglini, 2016).

Table 2 also displays storage options in microgrids, or storage used to enhance the mutual integration of microgrids. Fuel cells and batteries, rapidly co-developed based on graphene technology (Brownson, Kampouris, & Banks, 2011), can be integrated within households, but more importantly batteries will be integrated in microgrids to even out the variability of renewable sources by absorbing and possibly also uploading electricity (Delucchi & Jacobson, 2011). The important development of charging plug-in electric vehicles within microgrids (Honarmand, Zakariazadeh, & Jadid, 2014) may become a significant factor in advancing the deployment of DGRS. Most storage options supporting DGRS probably have minor landscape impacts, unlike storage infrastructures associated with large-scale CGRS (e.g. pumped hydro) (Castillo & Gayme, 2014; Gurung et al., 2016).

4. Required institutional changes

Establishing intelligent microgrids with RES is a complex innovation process. Innovation is not merely the introduction of new technology, but rather the construction of new socio-technical systems (STS) (Geels, 2004). An STS that maximises the development and use of renewables will be socially embedded in a completely different way from our current centralised, fossil fuel and nuclear power supply systems (Akorede, Hizam, & Pouresmaeil, 2010; Manfren, Caputo, & Costa, 2011). As explained below, current policies on renewables' deployment often follow the current organisation of power supply systems by focusing on CGRS. This review, however, focuses on DGRS implementation that is in line with the rapidly unfolding paradigm of systems with multiple energy sources in integrated microgrids as the key to decarbonising power supply (Bakke, 2016; Justo et al., 2013; Lasseter, 2011; Lund, 2014; Lund, Andersen, Ostergaard, Mathiesen, & Connolly, 2012; Siano, 2014; Wolsink, 2012; Zhang, Gatsis, & Giannakis, 2013).

In the development of intelligent grids, integrated microgrids, and geographically highly varying DG co-producers and consumers—co-operating 'prosumers'—are replacing and changing the social and organisational principles of existing power supply systems. This innovation requires new patterns of social practices and thinking (Adil & Ko, 2016), also with regard to spatial configuration (Wolsink, 2012).

The most fundamentally altered organisational principle is that there will be no single central public power grid, but many integrated 'microgrids', through which energy flows from different sources, regulated and fine-tuned to local demand within these microgrids (Karabiber et al., 2013). Large power plants will still exist, but primarily serve as backup capacity instead of central units around which the supply system is designed. This requires sufficient socio-political acceptance of the institutional changes needed for establishing DGRS to further renewable sources. This acceptance cannot be taken for granted. Existing practices and thinking, as evident in the organisation of the energy sector, including government liaisons, are blocking the development of RES (Jacobsson & Johnson, 2000). DGRS is already challenging incumbent energy companies in countries that are relatively successful in transforming their power supply (Cludius, Hermann, Matthes, & Graichen, 2014; Schoettl & Lehman-Ortega, 2011). Increasing ownership of DGRS by non-utility actors (Adil & Ko, 2016) implies loss of market share, and incumbent firms are scrambling to influence government policies in their favour (Geels, 2004; Simpson & Clifton, 2015). Hence, these innovations often face stiff resistance. Existing frameworks that emerged in the past, 'path dependency', are serving the interests of existing organisations creating institutional 'lock-ins' (Liebowitz & Margolis, 1995; Walker, 2000).

In RES, the full socio-technical regime includes three categories: actors, networks and institutions (Jacobsson & Johnson, 2000, p. 630). Incumbents in the sector are a product of past institutional choices; their existence and the way they operate reflect path dependency, and their strategies tend to build upon existing practices and structures. Institutions go beyond organisations; they are behavioural patterns and ways of thinking as determined by societal rules: 'the rules of the game in society' (North, 1990, p. 5). Nevertheless, organisations are often part of self-reproducing patterns based on underlying ideological values and norms. Institutions blocking innovations can be found in regulation, standardisation, existing infrastructure ('installed base' with high sunk cost), knowledge systems, and above all, policy frames. Unruh (2000) distinguished four categories of patterns of actors, networks, and rules in the 'lock-in': technological, industrial standards, the social system and governing institutions. All four demonstrate our current ingrained way of thinking about the power supply—electricity is generated in central power plants—and the entire sector involved in generation, transmission, establishing infrastructure and distribution has been organised following that ingrained pattern. Consequently, the lack of acceptance of the growing DGRS phenomenon is also manifested in current policies favouring CGRS. The focus on large-scale and centrally managed systems seeks to perpetuate the centralisation pathway, along with the accompanying highly hierarchical planning and decision-making. Box 1 and Figure 1 provide an example of CGRS based on centralised thinking. This institutional inertia would strongly affect landscapes because of the size of facilities and the huge required transmission capacity.

Box 1. Desertec is a prime example of the extension of centralisation thinking in RES deployment (Figure 1). Renewable energy is generated far away from energy demand. Large solar power plants in the Sahara generate power, which is exported to Europe through large high-voltage direct current (HVDC) power transmission lines. These hundreds of kilometres of transmission lines are a substantial alteration of landscapes, posing a problem for securing community acceptance. Such grid expansion in centralised frames urgently needs comparison on efficiency, acceptance and security with decentralised models (Samus, Lang, & Rohn, 2013). Moreover, centralised initiatives like Desertec, continue to be endorsed by 'a variety of stakeholders seeking their own particular brand of progress' (Van der Graaf & Sovacool, 2014, p. 26).

The required institutional changes also concern government actors and interventions. Not only a different perspective for national governments, but also local governments. Bulkeley and Kern (2006) recognise a required shift towards 'governing through enabling' in order to create new frameworks that are supportive of community initiatives. The latter is important because the neglect of landscape issues and community acceptance is inherent in large-scale CGRS initiatives. Locked in path dependency they follow the centralisation paradigm, further enhanced by project planning driven by market frames (Del Río & Linares, 2014) such as tenders on centrally defined large power plants. The institutional lock-in also includes our spatial planning systems, which is informing the main concerns of this review: how to create available space, and how to decide about that with high relevance to landscape values.

5. Landscape values

5.1. Landscape relevant institutions

Unruh's (2000) categories of 'social system' and 'governing institutions' are relevant for landscape values. Governance institutions concern legal frameworks, organisation of governments (departments,

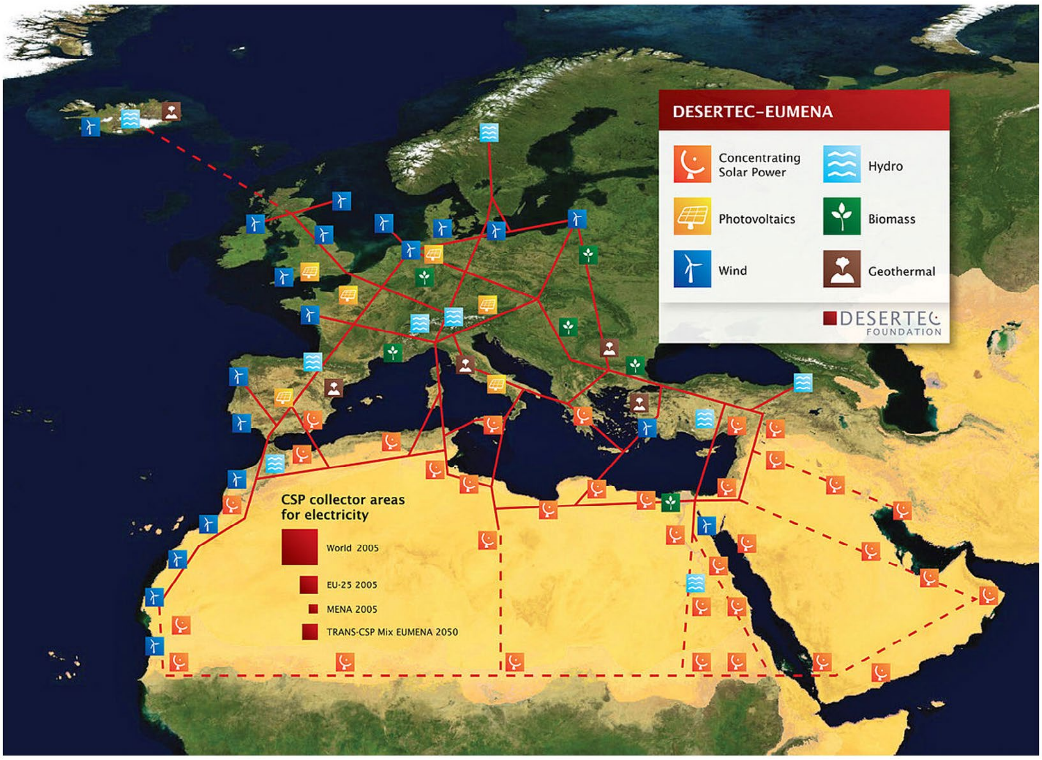

Figure 1. Desertec: Mega-infrastructure for supply of renewable power to Europe, the Middle East and North Africa. Source: www.desertec.org © DESERTEC Foundation [general use allowed by CC BY-SA creativecommons].

ministries), and patterns of policy intervention, whereas cultural values and socio-economic structures are part of social systems. Institutional arrangements affecting the deployment of DGRS include

- Legal frameworks on energy production and consumption, including prohibiting mutual delivery of electricity among consumers;
- The structure of the power supply sector (actors, networks);
- Financial regimes: taxation, fossil fuel subsidies, unstable and inconsistent RES procurement (Breukers & Wolsink, 2007; Simpson & Clifton, 2015), banking;
- Legal frameworks for land use and landscape justice (Jones, 2006);
- Spatial planning systems, with hierarchies limiting space-making for DGRS infrastructure.

The last two cover institutionalised patterns of thinking about landscape, space, spatial planning, justice and fair decision-making about infrastructure. Radical changes in energy supply also require a novel approach to analysing socio-technical pathways in relation to space (Walker & Cass, 2007). Previously studies have rightly associated energy landscapes with socio-economic and political power (Nadaï & van der Horst, 2010). Institutional, political and economic power structures are framing the ways decisions about RES and landscape are made, and existing energy infrastructure reflects these power structures in the landscape (Mels, 2014, p. 176).

Different kinds of ownership (Schlager & Ostrom, 1992)—of the space required for infrastructure as well as the infrastructure itself—are an essential element in creating access and shared control over sites and infrastructure. Renewable energies are *natural resources*; thus, scarcity is a fundamental issue in their management. Worldwide renewable sources are abundant (Delucchi & Jacobson, 2011), but for practical harvesting, distribution and consumption, the prime limiting factors are the available space

(MacKay, 2009) and social acceptance of land use for infrastructure (Palmas, Siewert, & von Haaren, 2015; Wolsink, 2013a). Dealing with spatial scarcity mainly depends on two factors:

- The socio-political acceptance of regimes that genuinely empower co-producers in the communities that invest and offer space for hosting infrastructure;
- The extent to which co-producers are free to implement infrastructure in their own way, making it acceptable in terms of landscape and justice.

5.2. Landscape and acceptance

Landscape is defined as the human habitat part of the natural environment, as seen and understood through the medium of our own perceptions (Bell, 1999). Nature and landscape are strongly connected in perception and valuation. Landscapes are understood as being either territory or scenery, but they should also be conceived as contested spaces, based on the bond between 'community, justice, nature and environmental equity' (Olwig, 1996, p. 630). Rural landscapes and nature in particular are strongly associated with idealised notions of a 'natural, pure environment', that is, 'spaces free of intrusive technology' (Cowell, Bristow, & Munday, 2011, p. 542). Landscape changes reflect social injustice and morality (Jones, 2006). Key elements in the processes of establishing RES are justice, fairness of process and mutual trust (Cowell et al., 2011; Wolsink, 2010a, 2013b). Trust is the pivotal element in community acceptance of infrastructure (Kasperson, Golding, & Tuler, 1992), which includes the treatment of landscape values in all RES infrastructure siting (Tables 1 and 2).

Social acceptance is central to the diffusion of all new energy innovation. This holds true for acceptance of the infrastructure as well as the required reorganisations of the power supply. It concerns the social acceptability of all social choices needed to create DGRS in intelligent grids, i.e. the acceptance of the institutional changes required to escape from the trap of path-dependent institutional constraints (Walker, 2000) that produce the 'carbon lock-in' (Unruh, 2000). However, it is also about a significant change in our institutional thinking and on-going behaviour in creating spaces for DGRS infrastructure while integrating landscape issues.

Social acceptance concerns all relevant actors, supporting as well as opposing innovations (Wolsink, 2013a) in three distinguished spheres of social acceptance (Wüstenhagen et al., 2007; Figure 2). The acceptance within society of all consequences of the innovation in the energy system based on renewables is determined to a considerable extent by the institutional arrangements for ownership and

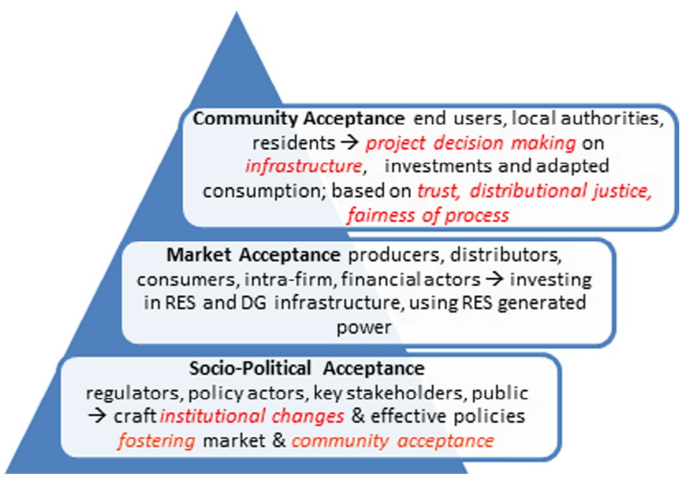

Figure 2. Three spheres of social acceptance. Italics: main relevance for landscape issues (Wüstenhagen et al., 2007, updated).

control: over DGRS by community actors in microgrids (top and middle, Figure 2), and over land use and landscape impact of the units (top, Figure 2). Establishing DGRS in microgrids, including making space for its infrastructure, is a problem of collective action. It has many similarities to the proper management of other natural resources and public goods (Ostrom, 2009, 2010). Low socio-political acceptance of restructuring institutional frames (bottom, Figure 2) is the main bottleneck for sound RES deployment (Delucchi & Jacobson, 2011; Wolsink, 2013a). The main resistance to institutional changes comes from policy actors and key stakeholders such as energy sector incumbents. Institutional changes are needed to foster market acceptance (middle, Figure 2) and—especially relevant for landscape issues—to foster and support socio-technical system matching with landscapes variations, which ultimately secures community acceptance. Market and community acceptance will also be shaped by the trust the actors have in the institutions and the actors guiding the transformation of the conventional energy grid into an intelligent grid.

5.3. Landscape as visual impact

From the beginning of the revival of wind energy in the 1980s, 'visual impact' has been recognised as the main issue in public acceptance (Thayer & Freeman, 1987; Wolsink, 1988). It is also pivotal in community acceptance of wind projects and transmission lines (Aas et al., 2014; Wolsink, 2013a). The proliferation of solar arrays has again emphasised the visual as a major topic in public and community acceptance (Chiabrando, Fabrizio, & Garnero, 2010; Scognamiglio, 2016).

Visual impact is conceptually a highly complex and frequently misunderstood topic in studies on RES. As a result of misunderstanding among policy-makers and developers, policies trying to address visual impact have developed into a major issue on socio-political acceptance. Common-sense 'knowledge' simply associates wind turbines and transmission lines with negative visual attitudes ('visual pollution'), as evidenced in many studies applying economic valuation approaches (willingness-to-pay) for visual impact (Ladenburg, 2010). Onshore wind power is preferably sited in the open countryside because open space delivers superior yields due to high wind speeds. Depending on the landscape relief, it also implies visibility of tall structures, which is automatically assumed to be a negative attribute of the turbines. This is an untenable assumption, as demonstrated by the Maehr, Watts, Hanratty, and Talmi (2015) study on emotional responses where wind turbines were assessed as less aversive and more calming compared to other industrial constructions. In line with the assumption that any visibility of wind turbines is perceived negatively, two other misconceptions linger: the equalisation of visual impact with mere visibility (Jensen, Panduro, & Lundhede, 2014), and the restriction of visual impact to the mere aesthetics of turbines or pylons.

5.4. Perceived landscape quality vs. technology aesthetics

Various studies attempted to quantify the effects of shape, colour, visibility and size on perceptions of wind turbines, in order to define the designs and configurations of 'acceptable' installations. Similarly for ground-based PV arrays, patterns with stripes or random patterns are being studied as a replacement for the typical orthogonal grid (Scognamiglio, 2016). Unfortunately, the assumption that visual impact is primarily understood as the aesthetics of wind turbines or PV arrays is a misconception. Visual impact is generally assessed in terms of infrastructure looking 'in place' or 'out of place' (Devine-Wright & Howes, 2010). Wider landscape concerns, such as disruption of a person's attachment to a place or perceived loss of amenity, also play a part. It is about changing the main character of landscapes, suffering from 'technology intrusion' (Cowell et al., 2011) or turning 'natural' or 'rural' into 'industrial' landscapes (Phadke, 2010; Thayer & Freeman, 1987).

Visual impact is not an assessment of infrastructure as such, but of landscape quality change invoked by siting of the infrastructure. It is primarily guided by the individual's assessment of the landscape at the site (Frantál & Kučera, 2009; Molnarova et al., 2012; Wolsink, 2007, 2010b), rather than the aesthetic quality of the structures. Betakova, Vojar, and Sklenicka (2015) found that the highest rated landscapes in terms of aesthetic quality received the lowest ratings after the addition of wind turbines, whereas increasing the number of turbines in the least attractive landscape had less impact.

5.5. Visual impact ≠ visibility

The second major misconception is the confusion between 'visibility' and 'visual impact'. Authors claiming to investigate visual impact usually merely look at visibility, implicitly using an inadequate and biased concept as a proxy for visual impact: 'The visual impact calculation consists in determining whether a renewable facility from the inventory can be seen' (Rodriguez, Montañés, & Fueyo, 2010, p. 241). Most studies apply GIS-based 'viewshed' calculations (Griffin, Denu, Guerry, Kim, & Ruckelshaus, 2015; Minelli et al., 2014). Studies of PV similarly narrow impact to 'visibility' and 'viewsheds' (Fernandez-Jimenez et al., 2015; Minelli et al., 2014).

Visibility and viewshed analysis do not incorporate most of the key visual concepts distinguished by Tveit, Ode, and Fry (2006): stewardship, coherence, disturbance, historicity, visual scale, imageability, complexity, naturalness and ephemera. In fact, any landscape change through RES infrastructure is considered a 'disturbance', sometimes combined with 'scale' and 'complexity' when size and number of constructions are taken into account. All other concepts contain cultural, social, historical and functional elements that have value only in 'the eye of the beholder' (Lothian, 1999). Hence, landscape values can be adequately evaluated only by including the beholder in the process of assessment and decision-making. Top-down designs that bypass the local community threaten trust relationships and landscape justice in the siting of renewables. Phadke (2010) provided a clear example how visual impact assessments based on viewsheds acted as a catalyst for opposition.

5.6. Avoiding objectification: co-production

While references in Sections 5.3–5.5 highlight visual impact as a dominant issue in RES developments, is it possible to incorporate 'objective' measurements in planning support tools, like Multi-Criteria-Analysis? (Gamboa & Munda, 2007; Griffin et al., 2015; Höfer, Sunak, Siddique, & Madlener, 2016). The individual's valuation of the countryside varies in time, from person to person and from place to place. Bell's (1999) definition of landscape finds visual impact to be a fundamentally subjective assessment, while Lothian (1999) recognised that expert approaches imply the characterisation of landscape as an object. Visibility studies that follow this approach are using tools for visual representation that include local stakeholders' views in assessments of suitable landscapes, sites and infrastructure configurations (Grassi & Klein, 2016).

The lingering 'objectification' and the use of 'visibility' as proxy for impact reveals an inclination towards continued centralised control in energy planning. Such institutionalised technocratic policies demand the development of 'tools' to 'calculate' the best RES sites. Criteria are set for establishing renewable energy projects with limited environmental impact taking into account technical and geological constraints (Baltas & Dervos, 2012). Studies that apply such methods automatically tend to focus on centralised options, like solar plants, resulting in PV landscapes (Figure 3).

The trend can be interpreted as following existing energy planning institutions, whereby authorities try to reinforce central control over planning energy infrastructure. However, centralised planning brings with it projects initiated by community outsiders, which increases contestation of these projects, developed without meaningful community engagement or serious consideration of landscape concerns (Fast et al., 2016). All studies on mainstreaming RES diffusion and social acceptance emphasise the importance of engagement (Devine-Wright, 2011; Haggett, 2009; Wolsink, 2013a). Community outsider projects resulting from government lead project tenders, however, tend to avoid engagement (Del Río & Linares, 2014), and as a result provoke resistance. Instead of 'objectivised' landscape assessments within centralised and hierarchic decision-making, fostering community acceptance of DGRS requires co-production in open processes.

Figure 3. ‘PV landscape’ LesMées, Alpes-Haute Provence, France.

Box 2. PV integrated in landscape.

The options of using space for PV close to communities remain underutilised in the centralised visions of PV (Figures 1 and 3). Integration with landscape and other community values offers opportunities for securing the space close to communities. The option in Figure 4(A) shows the results of co-production of DG infrastructure and of co-production of energy close to consumption. Rooftop PV panels are part of a wider energy system also including storage and other DGRS options, owned and managed both privately and collectively. This emerging microgrid—based on collective ownership, multifunctional use of space, and integration in the built environment—reduces landscape impact and enhances community acceptance. Similarly, Figure 4(B) shows the integration of solar panels in avalanche barriers around slopes for winter sports (Michel, Buchecker, & Backhaus, 2015). The infrastructure fits well with the landscape, which has already been adapted for tourism. It is co-producing power for the community and the ski lifts, with relatively high community acceptance.

5.7. The landscape–infrastructure mismatch

The key question in the process of co-production of space for DGRS is the following: *Does the infrastructure fit well within the landscape, according to the opinions of the community that identifies itself with the place?* Any visibility calculation, planning schedule or procedure that does not place the ‘beholders’ at the centre of the decision-making process will struggle to succeed. Centralised planning that favours large solar power plants, for example, significantly reduces the space available for solar infrastructure, as community residents seem to prefer larger distances to residential areas, reducing visibility, in cases of PV plants (Carlisle, Solan, Kane, & Joe, 2016). Replacing centralised installations with co-production can improve deployment. Box 2 and Figure 4 give three examples how co-production can make space for DGRS within the community. Box 3 outlines a future option for reducing landscape impact of high voltage (HV) transmission lines through negotiations with the affected communities.

(A)

(B)

Figure 4. Solar PV with community integration, landscape compatibility and high community acceptance. (A): Germany, Baden-Württemberg; (B): Switzerland, Wallis. (Photo: Ananina Michel).

Box 3. Negotiating HV transmission lines.

DGRS with intelligent decentralised optimisation of production and consumption can reduce the need for long distance HV transmission. Centralised RES generation, including large-scale renewables at remote locations (e.g. offshore wind), is currently under pressure in Germany due to community protests against transmission lines (Stegert & Klagge, 2015).

Low community acceptance of HVAC lines, further aggravated by central planning, can be improved by empowering communities. Co-production, in this case negotiations on transmission infrastructure, should focus on the type of transmission lines, tracks, and on replacing old lines with new ones that fit better with the landscape. The alternatives include limiting capacity of transmission lines, by using DC instead of HV lines (MacDonald et al., 2016), or reducing long distance transmission capacity by increased DG deployment (Lopes et al., 2007). Other options are lines underground instead of using pylons (Zaunbrecher, Stieneker, De Doncker, & Ziefle, 2016), and possibly replacing old lines with new coaxial superconducting HVDC transmission, also buried underground (Thomas et al., 2016). This is an example of securing buy-in for additional capacity by empowering the affected communities to negotiate the terms for replacing existing open-air transmission lines.

6. Discussion and conclusions

The merit of community involvement and co-production is illustrated in Boxes 2 and 3. Unfortunately, the current trends in power supply development still reflect the carbon lock-in. Europe is witnessing a movement towards large-scale CGRS, increased ownership by multinational companies (Szarka, 2007), and market-based centralisation in RES governance (Ćetković & Buzogány, 2016). The neo-liberal approach of using auctions for issuing permits for wind farms is one indicator and trigger (Del Río & Linares, 2014), and it is already slowing down cooperatives in establishing DGRS in Germany, despite their success during the last two decades (Mignon & Rüdinger, 2016, p. 486). This strategy has reduced the potential for securing community acceptance, and centralisation also increases the number of landscape and other environmentally motivated protests (Anshelm & Simon, 2016). The differences between CGRS and DGRS approaches reflect irreconcilable differences in normative aims (Lilliestam & Hanger, 2016; Wolsink & Breukers, 2010). The growing body of literature on RES, covering many national contexts, demonstrates that participation is pivotal—both for inclusion of landscape values and for establishing high rates of DGRS within the socio-technical system (STS) of power supply. Trust and confidence are vital for consumers, investors and those affected by RES. Lack of trust decreases the proliferation of sustainable generation in energy systems (Büscher & Sumpf, 2015) and significantly hampers the progress of negotiations and participatory processes in RES (Friedl & Reichl, 2016).

- *Conclusion* 1: Scaling up development of low-carbon infrastructure can be accelerated through institutional conditions that enable and encourage resource users
- to engage in co-production of DGRS and
- to engage in creating space for the required infrastructure.

As in social-ecological systems, a STS similarly combines social organisation and the implementation of infrastructure that utilises specific technologies (Geels, 2004). Co-production and the use of renewable energy is like any other common pool natural resource use (CPR), and a rich framework of institutions can be found in the theory of sustainable use and management of natural resources in social-ecological systems (Ostrom, 2009). The essentials of developing DGRS show agreement with the management and governance principles of CPR: polycentric governance and self-governance (Ostrom, 2010). In socio-ecological systems, social and ecological components are interconnected, and the broad variety and complexity of social and natural components necessitate diversity and polycentricity in governance regimes (Dietz, Ostrom, & Stern, 2003). Ostrom (1999) describes how the proper management of highly valued public goods can become disrupted when centralised and hierarchic models of management are applied in policy. Fundamental characteristics of CPRs are complexity and variety. Whereas CGRS approaches tend to try to escape from complexity, power supply systems based on DGRS and intelligent grids will show increasing complexity with a broad variety of generation units, located in multiple types of ecological and social conditions.

Conclusion 2: The application of CPR theory on RES in intelligent grids shows great potential for enhancing the analysis of the power supply and urgently needs further elaboration.

Several studies have recognised this potential; some with a socio-technical approach (Bauwens, Gotchev, & Holstenkamp, 2016; Goldthau, 2014; Wolsink, 2012), others with a specific legal-institutional approach (Lammers & Heldeweg, 2016) or a specific socio-ecological focus on the system (Hodbod & Adger, 2014). Integrating DGRS from different variable sources and varying demand requires co-production, which is considered an essential element of any good governance regime (Ostrom, 2010). Access to the resources of renewable energy is primarily determined by the scarcity of the considerable space required for the infrastructure and power generation (MacKay, 2009; Palmas et al., 2015).

Conclusion 3: The prime scarcity factor for establishing a power supply based on RES is space.

Conclusion 4: Evaluation of the space that needs to become available, and the dominant attribute for accepting land use for energy functions, is a good match with 'landscape'.

In order to achieve this 'good fit', co-production is a necessary requirement for securing community acceptance. Strong commitment of all affected actors is needed: those with a stake in land use (primarily proprietors), but also anyone with substantial place attachment as well as members of the broader community. This is a complex undertaking and the experience is limited, because both land use and RES ownership are ruled by varying property rights regimes (Schlager & Ostrom, 1992), both inconsistent with existing energy planning. For RES, these stakes are also different from other kinds of land use because ensuring the free flow of the resource (radiation, wind, water streams, geothermal layers) implies certain 'resource rights' that translate into land uses (Vermeylen, 2010). As Ostrom (2010, p.10) observes, 'citizens are an important co-producer. If they are treated as unimportant or irrelevant, they reduce their efforts substantially.'

Conclusion 5: Establishing DGRS within intelligent grids, with infrastructure that corresponds to the landscape values of 'beholders', is incompatible with hierarchical decision-making and centralised planning.

CPR studies show that simple governance strategies, applied in the name of efficiency, which rely on imposed markets or on centralised command and control mechanisms, tend to fail (Ostrom, 1999). Neo-liberal frames that set market conditions and uniform standards as the main governance regime are slowing down RES implementation in many countries, particularly in those that favour centralised policies and large-scale projects (Ćetković & Buzogány, 2016; Szarka, 2007). Indeed, lack of meaningful engagement and neglect of landscape values are the direct result of the neo-liberal approach to RES policy (Del Río & Linares, 2014; Fast et al., 2016).

Regulation should describe general policy-making frames without being prescriptive. Particularly top-down decisions on what should be constructed, where, and by whom, are decreasing the geographical fit of DGRS. Such directives in the case of RES replicate the traditional approach to energy management, including counterproductive social constructions of 'the public', its perceptions and motives (Brondi, Sarrica, Caramis, Piccolo, & Mazzara, 2016). Central policies should rather provide preconditions favouring engagement and options for establishing community and prosumer-oriented power supply systems.

Acknowledgements

The author thanks an anonymous reviewer for critical and valuable comments.

Disclosure statement

No potential conflict of interest was reported by the author.

ORCID

Maarten Wolsink http://orcid.org/0000-0002-5058-6906

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