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Distributed energy systems as common goods: Socio-political acceptance of renewables in intelligent microgrids

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A B S T R A C T

The future social-technical system (STS) of power supply based on renewables depends heavily upon the rapid emergence of Distributed Energy Systems (DES). The prime object of Social Acceptance processes of renewable energy innovation becomes the issue of how to incorporate DES. The realization of this transformation requires the escape from locked-in hierarchy and standardized design of the centralized grid. This review elaborates the advanced conceptualization of Social Acceptance, particularly its socio-political layer. High diffusion of DES in intelligent microgrids leads to polycentricity replacing hierarchy. Therefore, the main object of 'socio-political acceptance' concerns institutional changes replacing hierarchy by co-production within STSs applying DES. Renewables become 'common goods' in such systems, instead of 'private' or 'public' goods. Systems providing 'common goods' like renewables -that are natural resources-show similarities to socialecological systems, the self-governing entities in common pool resources theory. Application of this institutional theory to co-production in DES leads to the following conclusions on socio-political acceptance. Renewables generation, integration, storage, intelligence and demand response require a shift towards co-producing prosumers. Electricity as an economic good must be redefined from commercial private commodity delivered in a public grid towards a co-produced common good. Essential for common prosumer-based DES is the application of peer-to-peer deliverance (P2P). Policy must avoid to interfere in this and also should remove legal obstructions and transaction costs for P2P and coproduction. As space is the prime scarcity factor for DES, prosumers' communities should also be empowered in co-producing land use decisions for construction of their DES infrastructures.

1. Introduction

The development of the future low-carbon power supply based on renewables will emerge in an operating environment in which generation based on renewables is dependent on the rapid emergence of Distributed Energy Systems (DES). 'Distributed', a concept beyond 'decentralized', was introduced by Ackermann et al. for 'distributed generation'(DG) [1]. In addition to generation units, DES also includes distributed storage, distributed schemes of internal demand response (DR), and adjacent infrastructures connecting and controlling the use of storage, generation, and transmission capacities as well as multi-directional energy flows.

Distributed Generation was originally defined as power generation units that are not part of a centralized power system, which implies more than simple decentralized generation locations [2]. In addition to a large geographical dispersion, it concerns generation close to demand [3] and direct connection to the distribution network, possibly at the customer side of the meter [1]. Consequently, implementation of renewables in DES is not simply installing new hardware; increasingly it has come to imply broader interaction with 'distributed actors' [4]. This concerns institutional changes, going far beyond the 'techno-economic paradigm' shift required for the complete transition to renewable sources [5]. The main challenge is that DES is based on entirely different organizational principles than the existing centralist and hierarchical system of the electricity supply. Instead of being simply 'decentralized' they become part of a hybrid global system, as "the clean and economically sound electric energy system of the future will be those flexible enough to allow for a spectrum of hybrid modes of operation and investment" [2], p.4504]. The multitude of centres of decision-making at different levels (polycentricity, section 2.4), the variety and the flexibility, mandate a full paradigm shift in designing the power supply system of tomorrow [2,6,7].

The realization of this transformation is extremely difficult. The new paradigm and all the new elements of the new system are not simply technological substitutions but fundamental innovations. The new

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Abbreviations

AC	Alternate Current
AMD	Advanced metering device
CPR	Common Pool Resources
DC	Direct Current
DES	Distributed energy system
DG	Distributed generation
DR	Demand response
DSM	Demand side management
DSO	Distribution system operator
ESCO	Energy service company
GS	Governance (sub)system
HV	High voltage
LEM	Local electricity market
LV	Low voltage
P2P	Peer-to-peer
PV	Photo-voltaic
RS	Resource (sub)system
RU	Resource units (subsystem)
SA	Social acceptance (process)
SES	Social-ecological system
STS	Social-technical system
U	Users (subsystem)

elements concern both *social innovations* – new organizational structures, new division of property, management and control – as well as new technologies and hardware. Most of the new elements are subject to strong institutional lock-in factors [8,9], precisely because these concern social innovation [10] and the sunk cost liabilities in existing infrastructures. Heavy resistance in society against the development and implementation of many elements is coming to the fore, counteracting the many initiatives and movements supporting fundamental changes in the power supply system that represents the new paradigm.

Since the 1980s the struggles and conflicts around decisions to implement the new elements have been studied within the concept of processes of 'social acceptance' (SA). The general conceptual framework for SA [11] makes a distinction between fundamentally different processes at three levels, but recent energy innovation research and new developments in low-carbon power supply show that the original definition of SA must be tightened up by elaborating the fundamental differences and the relations between the three levels [12]. The objective of this article is to elaborate the concept of SA of renewables innovation, with an emphasis on the institutional conditions that affect – and often obstruct – the social innovation component. Social innovation mainly takes place at the levels of market- and community acceptance, whereas the required conditions to support innovation at these levels must be shaped at the level of socio-political acceptance [12].

2. Towards social acceptance 2.1

2.1. Object: beyond single source projects

Originally Social Acceptance research focused on public attitudes towards single techniques or source, mostly wind [13]. With the noted limited significance of the role of public support in explaining and understanding what is happening in processes of acceptance, the perspective fundamentally changed. The enhanced conceptualization [11] shifted the focus towards processes involving many, diverse actor groups. In this concept of SA2.0 actors take decisions based on dynamic insights that are affected by actions by other actors, under frequently changing conditions.

Currently a further enhancement is needed regarding the acceptance 'object', going well beyond questions of SA of a single renewables technology. All changes in energy systems required for the implementation of renewables must be covered, including other forms of organization and infrastructures needed to make the implementation of renewables possible. Hence, the object of SA2.0 is rapidly changing into one that concerns all systemic changes needed to redesign our entire energy supply systems and to move them away from carbon-based sources towards multiple integrated renewable sources. This colossal task demands an analytical approach that can address all crucial elements in the *Socio-Technical Systems* (STS) [14] of energy supply. For SA2.1 the object of acceptance is defined differently:

- It requires research that looks *beyond single* power generating *technologies*;
- It increasingly has to focus on *processes* with *many actors* at *multiple levels.*

SA of renewable energy innovation should be understood as "a bundle of processes of decision-making on issues concerning the promotion of –or counteraction against– new phenomena and new elements in the transformation of current energy systems." [12], p.287). The objects are all elements of systems of integration of different renewable sources and the acceptance of new structures – institutional regimes – that enable and support a rapid transformation to a sustainable energy system replacing the fossil-nuclear system of the past. In SA research the most investigated objects are still wind projects, and remarkably with a focus on resistance among residents, and sometimes these are even designed around persisting prejudices (e.g. 'nimbyism') about the role of local residents [15]. Unfortunately, the potential pushbacks against renewables' innovations are not likely to be found this way. Local public resistance against an energy companies' wind scheme is merely a special case to investigate, as it does not address the most significant issues in SA processes. Such studies have the following limitations – possibly generating misunderstanding:

(a) the *one actor-group* focus implies ignoring the role of all other actors in the project development;
(b) focusing on *resistance* implies that other positions are taken for granted and not well understood, such as initiatives, participation, support, tolerance [16];
(c) the focus on *one facility* suggests that opposition to one project reflects resistance to the technology as such;
(d) as the single facility also implies one *previously selected site*, it cannot reflect the attitudes towards similar wind farms at sites with differently appreciated landscape impacts;
(e) a *wind* project implies ignoring the relationship of wind with other sources and adjacent infrastructures (e.g. transmission, storage, demand response);
(f) most case-studies concern projects *operated by an incumbent* in the current power supply system, whereas projects initiated and operated by other actors generate substantially deviating responses;
(g) there is a focus on the *permission granted by a certain tier of government,* whereas there are many more decisions in the acceptance process of a wind farm.

All elements (a–g) are variables that affect the appreciation of a project, and not only for the local public, but for all actors involved in the process. Hence, the findings of a local public attitudes study cannot be generalized to Social Acceptance of renewables. In this case not even to SA of wind power, as the technology is only one characteristic of the project. Other system characteristics may be equally important, such as the type of landscape of the site, the type and origin of the investor/owner/manager of the facility, and who will be consumers of the generated power. As SA is a process, the institutional settings that frame the decisions particularly matter, such as the engagement of the host community and the potential users of the generated electricity. For example, forms of 'tokenism' or outright efforts of overruling applied by community-outsider developers and authorities [17], with the naïve perception that this would push the project forward [18], can affect potential community acceptance. Rarely investigated, but whether in acceptance processes the 'public' is the crucial decisive actor, is questionable [19].

Hence, the relevant object of acceptance studies rapidly moves away from single sources projects towards integration of different sources into a new emerging socio-technical system. It requires the recognition of polycentricity (section 2.4) and multiple-actors in the different layers of social-acceptance of renewables' innovation.

2.2. Three layers of acceptance

The shift in the acceptance object towards the use of several renewable sources, combined with the installation of adjacent DES infrastructure, further reduces the relevance of single source, single actor, one-shot case studies on the actor's position. The dynamics of the actions and the preferences of all actors in cases of implementing integrated DES are shaped by the framework of institutional conditions of the process. These 'rules of the game' [20, p.5] can be favourable or discouraging in different ways. For example, how renewables are pushed on the market (e.g., subsidies, certificates, auctions or tenders of feed-in permits [21,22] may trigger aversive reactions at the levels of market acceptance as well as community acceptance. The same applies to top-down land use planning executed in coercive strategies, which is a violation of procedural justice [23–25]. Even more importantly, due to the emergence of DES that integrate various renewable sources with different forms of storage capacity and with systems of flexible adaptation of demand, the SA issue is rapidly shifting towards the question of decisions that open up opportunities for integrated implementation of multiple renewable resources. In this case, locked-in institutional frames (e.g., legislation, the structure of the current grid) are major generators of resistance.

The key question is how to elaborate the new paradigm so that it will succeed in securing acceptance among society at large on the required institutional changes, the construction of all new hardware, and the new organizational design of the power supply system. The object of SA of renewables' innovation is complex and multidimensional. For that reason, the original conceptualization of SA2.0 [11] introduced the distinction between three dimensions: community, market, and socio-political acceptance. The gradual shift in the of object of SA, from single resource power generating facilities towards DES integrating different resources [26] combined with storage and demand response [27] asks for an upgrade of the SA concept.

Due to increasing complexity the distinction between three dimensions becomes even more significant, also methodologically, as the nature and the strength of the mutual influences between the processes in the different levels can only be found and understood if they are clearly conceptually distinguished first. All three levels are characterized by:

- different processes, within
- different procedural frames (legal frames, actor's strategic frames),
- concerning different objects of acceptance;
- with different sets of actors operating at each level.

Some actors appear at more than one level, but they do so in different roles. For example, traditional energy companies operate in markets but also as stakeholders and lobbyists at the socio-political level [28].

Further elaboration of the concept of SA reveals that the three dimensions are in fact a manifestation of multiple layers (Fig. 1). The most important objects of socio-political acceptance concern 'regime changes', which are crucial for real transition [29]. The multi-level configuration of SA processes emphasizes that conditions set within the socio-political layer (e.g., defining market conditions and empowering community actors) are affecting acceptance processes in the two other layers. The regime change concerns the institutional changes required for the transformation of the power supply system. In paradigmatic terms [2,5,7], this focus implies the abandonment of the centralized, hierarchic system, and the establishment of polycentric, hybrid, flexible, and adaptive systems that facilitate the deployment and development of DES in intelligent microgrids [4,30] with strong variety, flexibility, and resilience. These hybrid and intelligent microgrids with large numbers of diverse DES units require new organisational principles and structural changes, such as institutional changes in spatial planning, due to the enormous and radically altered land use requirements [25].

2.3. Acceptance: a dynamic process

SA is about issues concerning the promotion of – or counteraction against – new phenomena and new elements in the transformation of current energy systems. The recognition of SA as a bundle of complex, dynamic, and interdependent decision-making processes, instead of a simple actors' preference in one specific domain, is crucial. All actor's positions are dynamic; actors react to each other and to the developments in the other two layers of SA (Fig. 1). Even the main overall object, 'energy innovation', is dynamic, as it is a process itself.

Power supply has evolved from the microgrids of the late 19th century towards a highly centralized system in the 20th century [31]. However, even as it continued to develop with several of incremental innovations in technology, its structural design has remained largely unchanged [8,32]. This core design is distinguished by a highly centralized structure of generation and monopolistic top-down distribution (standardized in most countries from 'backbone' HV transmission to distribution of 220 V/50 Hz AC), including fully formalized separation between suppliers and consumers (fixed in legislation) with metering within the territory of consumers owned and controlled by the suppliers and corresponding tariff systems based on centralized accounting [33].

Incidentally some new components have been introduced (e.g., interconnection of power grids, introduction of nuclear power, the rise of gas, and privatized generation); however, following mainstream classification of innovations [34], these merely concern 'architectural' innovations, which must be distinguished from the innovations required for the widely proclaimed 'energy transition' [28,29,35]. The latter calls the basic design and the core concepts of the current centralized power supply system into question. Such changes entail a systemic reorganization, accompanied by the elaboration of new components, i.e. 'radical innovation' [34].

This innovation is primarily replacing the principles of a few large, interruptible generation capacities that follow demand, by principles derived from numerous varying resources following natural conditions. Furthermore, because of the numbers, the variety, and spatial dispersion, the uniform structure of the grid is replaced by multiform structures with a polycentric design. Both changes assign a prominent role to distributed generation renewables' systems and adjacent DES. Real paradigmatic changes come to the fore, and the literature on innovation highlights that innovation is neither the invention nor diffusion of technology but rather the development of *new ideas* materialized in products and services that become socially accepted, replacing previous products and practices [36].

2.4. Polycentricity replacing hierarchy

Any claim of a transition in the STS of the power supply implies that

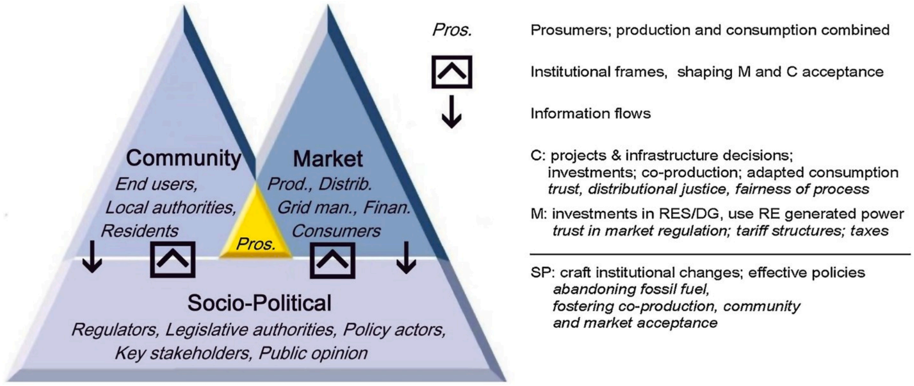

Fig. 1. Three multi-layered dimensions of SA, with significant actor groups [12].

the core elements of the paradigmatic change all become objects of Social Acceptance. Whereas the distinction between the three principal dimensions of SA has become mainstream (Fig. 1), the recognition of the dynamics and the process character of SA should have been the purport as well. Recent attempts to elaborate SA have proposed to position the three dimensions as layered vertically, reflecting different processes and arenas. These multiple layers may often relate to geographical scales – or might easily be interpreted as the aggregation level of the political process and the size and scale of the actors in the processes. However, such vertical ordering of the layers may give rise to the crucial misunderstanding that these layers reflect hierarchy: large scale/central/national/international on top (powerful, deciding, and steering) and small scale/local/decentralized at the bottom (dependant, following, implementing). Generally speaking, research indicates that the downscaling and distribution of responsibilities in governance by means of decentralizing powers from national towards regional and local levels adds significantly to the capacity and willingness of nations to achieve renewables' deployment [37,38]. However, DES should not simply be understood as 'decentralized' but as 'distributed' [2], which implies neither centralization nor decentralization, but rather polycentricity in governance [13,39,40].

It concerns fundamental shifts in control and management of the STS, and also models in which community and market acceptance become mixed through the emergence of 'prosumers' [41–43]. Because of its crucial role in the creation of DES by co-production at the level of implementation, the socio-political layer can best be placed at the bottom as a foundation (Fig. 1) – serving, supportive, encouraging – instead of at the top –suggesting central and top-down control. The move away from hierarchy in the governance of power supply is discussed in section 7.3.

The conceptualization (Fig. 1) shows the multi-level character of social acceptance processes, emphasizing that conditions (e.g., defining market conditions, or empowering local actors) set within the socio-political layer are affecting acceptance processes in the two other layers. For example, the literature widely agrees about the notion that institutional frameworks generally should foster stakeholder and community engagement (participation, co-production, empowerment, inclusiveness) in projects. The required co-production in establishing new renewables' DG and adjacent DES infrastructure concerns *co-production* in generation and management of energy, and also *co-production* in creating and maintaining infrastructures. The latter concerns co-produced investments and provision of space – the prime scarcity factor for renewables [25]. Flows of information about practical experiences and the needs for setting the right conditions and DES deployment must inform socio-political acceptance processes.

3. Institutional theory: common-pool resources (CPR)

3.1. The SES framework

The shared object of SA in all three layers is that it concerns all elements of innovation required for the establishment, use, and maintenance of power supply STS's with substantial DES. The most prominent implication is the acceptance of the necessary conditions for stimulating innovation processes, of conditions needed for implementation, and the acceptance of the consequences the implementation. These are processes of acceptance of paradigmatic and institutional changes associated with the prominent status of distributed generation and all other characteristics of DES. It concerns acceptance of institutional changes: restructured markets, new taxing systems, energy legislation, education systems, spatial planning systems, energy governance frames, redefined property regimes in power supply, etc. It even concerns acceptance of 'creative destruction' [44]; which refers to infrastructure assets (e.g. central power plants), but also major rearrangements in management and governance structures, including disempowerment of dominant actors.

As described in section 2.1 most investigations of SA still involve one-shot case studies that focus on only one layer/scale, analyse static actor positions, and commonly highlight 'the public', which already is an overly general and problematic group definition [13,45,46].

For a theoretical approach that focuses on institutions and escapes from the abundance of one-shot case studies without analysis of dynamics, with only the focus on an actor group and with the emphasis on one decision center on one level (see section 2.1), we will use Ostrom's Common Pool Resources (CPR) theory. Crucial elements in CPR theory are the focus on multiple layers and polycentric governance (see section 2.2 and 2.4), on the dynamics and broad variety in systems of distributed energy, and the recognition of renewables as a 'common good' [25,30, 47–52]. 'Common' refers to a type of goods of values provided by social groups collectively operating outside government control and private property considerations (section 6.2). The different types of goods need different types of institutional framing and different types of governance. For social-ecological systems with decreased centralised leadership, the most important function of polycentric governance is that it furthers self-organising processes for environmental governance [53].

The first reason to use CPR theory is that renewable energy flows really are natural resources, and it is solid with empirical evidence from many other natural resource studies. Second, the concept of *social-technical systems* shows similarity with the concepts of natural or human-made *social-ecological systems* (SES), the cornerstone of CPR theory [54–57]. DES are complex STS's with multiple interacting users aiming at optimal use of natural resources. They belong to the category of SES with human-made infrastructures that provide common resources, like irrigation systems [58].

The theory of CPR management is fundamentally institutional with a multi-level perspective, which is crucial for studying SA processes [12] and potential transitions [29]. A DES is an STS for sustainably harvesting and using renewable energy, so it perfectly fits into the SES analytical framework, with the same variables (Table 1) that are defining four subsystems and their interactions (Fig. 2).

Table 1
Subsystems and 2nd-tier variables in Distributed Energy Systems based on renewables.

	SES label [56,57]	Code [56]	STS variable in case of DES
Subsystem	Resource System[a]	RS[a]	Renewables' DES[a]
2nd-variables	Clarity system boundaries	RS2	Microgrid connection
	Human constructed facilities	RS4	DES infrastructure
	Productivity of system	RS5	Flows renewables, capacities of generation and storage
	Equilibrium properties	RS6	Energy buffers, DR, size and flexibility storage capacities
	Predictability system dynamics	RS7	Seasonal and daily patterns
	Storage characteristics	RS8	Type and size storage facilities
	Location	RS9	Spatial configuration and availability resources
Subsystem	Resource Units[a]	RU[a]	Electricity and Capacity[a]
2nd-variables	Growth/replacement rate	RU2	Variability renewables' flow
	Economic value	RU4	Common good (internally)
	Spatial distribution	RU7 (A)	Geographical definition resource
	Temporal distribution	RU7 (B)	Seasonal, daily, meteorological variation
Subsystem	Governance System	GS	Governance System
2nd-variables	Government organizations	GS1	Space, energy, nature permits issuing governments/agencies
	Non-government organizations	GS2	Energy companies, DSO, ESCO's, civil society organizations
	Network structure	GS3	Microgrid structure, P2P-delivery
	Property right systems	GS4	Property rights energy infra, land-use and buildings
	Operational rules	GS5	Local market defined and P2P-delivery operated by Intelligence
	Collective-choice rules	GS6	Microgrid collective governance
	Constitutional rules	GS7	Legislation and basic-contract
	Monitoring & sanctioning processes	GS8	Intelligent metering and distributed accounting
Subsystem	Users	U	Prosumers
2nd-variables	Number of users	U1	Number of prosumers
	Socio-economic attributes	U2	Socio-economic attributes
	History of use	U3	Path-dependency of lock-in (e.g non-P2P delivery, metering) in public grid
	Location	U4	Land-use property conditions
	Leadership/ entrepreneurship/ mental models	U5	Leadership/entrepreneurship/ innovative orientation
	Norms/social capital	U6	Norms/social capital
	Knowledge of SES	U7	Knowledge of STS (renewables, DES, demand, and intelligence)
	Dependence of resource	U8	Dependence on electricity
	Technology used	U9	Generation, storage, metering, DR and data-processing technology

[a] Selection of 2nd-tier variables based on relevance of socio-political acceptance.

As this review concerns 'socio-political acceptance', our main object of acceptance concerns institutional changes. In power supply the centralized hierarchical model is still the dominant paradigm, with a strong lock-in factor. As outlined in section 2.2 the three SA layers do not imply any hierarchy, so socio-political acceptance is positioned at the bottom (Fig. 1) as a foundation for SA. CPR-studies also clarify why renewables innovation usually does not benefit from central top-down direction from above, as they have strongly falsified the assumption that organization itself requires central direction [59]. Required institutional changes come to the fore at all three levels, like redefining the choice sets in markets or effectively empowering citizens for co-production of renewables. Changing the regimes [29] and the 'rules of the game' [20] in community and market acceptance processes, however, is the main responsibility of actors operating at the socio-political level. It concerns, for example, changing the restrictive legislation that favours centralized power supply and tends to obstruct newly emerging initiatives of co-production by prosumers. The latter are in fact an overlap of market and community acceptance of DES (Fig. 1, centre).

3.2. Four subsystems in the social-technical system

The framework of systems providing common good natural resources, such as any social-technical system providing 'renewables' with DES infrastructure, contains four interrelated subsystems (Fig. 2), each defined by 8 variables, 10 types of interactions, and 3 domains of outcomes (selection shown in Table 1). This review focuses on the 'software' subsystems, in particular the *users* or actors (***U***) and the *governance system* (***GS***). Two subsystems constitute the 'hardware' of the system. Within the *resource system* (***RS***) the crucial variable is the set of physical characteristics of the human-constructed element (***RS4***) [57], i.e. the DES infrastructure. ***RS*** also concerns the natural conditions that determine the opportunities for harvesting energy, such as physical geography variables connected to the location (e.g. resources availability, like solar radiation, wind, marine energies, geothermal, hydro) and other resource factors, such as equilibrium properties, predictability of system dynamics, and options and characteristics of storage capacity within the system [56], p.421), that depend on the design of the infrastructure. The geographical resource conditions can vary quite a bit from location to location, so the mix of technologies and the adjacent DES infrastructure will be very diverse. A pivotal physical component defining STS based on DES is the size and type of 'space' needed for the DES infrastructure [25].

The *spatial* and *temporal distribution* of the resource comes to the fore as the most challenging variable in the *resource units* subsystem (***RU***; Fig. 2). The *growth or replacement rate* is very demanding as renewables are based on flows of energy and a very large *number of units*. Renewables naturally have a favourable replacement rate, but as the generated power can only be used in real-time, the *economic value* fluctuates widely, even within the hour. Storage capacity, the implementation of Demand Response – instead of Demand Side *Management* (DSM) [60] – and an internal accounting and settlement system for the individual contributions to the production, the peer-to-peer delivery, and the consumption of the commonly produced electricity, become essential elements (Section 6). These ***RS*** variables define the key to *equilibrium properties* and *system predictability* (Table 1). Section 3.4 describes how these are fundamental needs in DES that are covered by the intelligence in the microgrid.

The 'software' in the STS consists of two subsystems, which are equally as important as the hardware. Simultaneously they strongly affect the effectiveness of the hardware, because infrastructure is human made, and the design and the existence of both ***RS*** and ***RU*** largely depends upon the users (subsystem '***U***', the prosumers; Fig. 2) as well as the decisions taken in governance subsystem. The following sections discuss these subsystems.

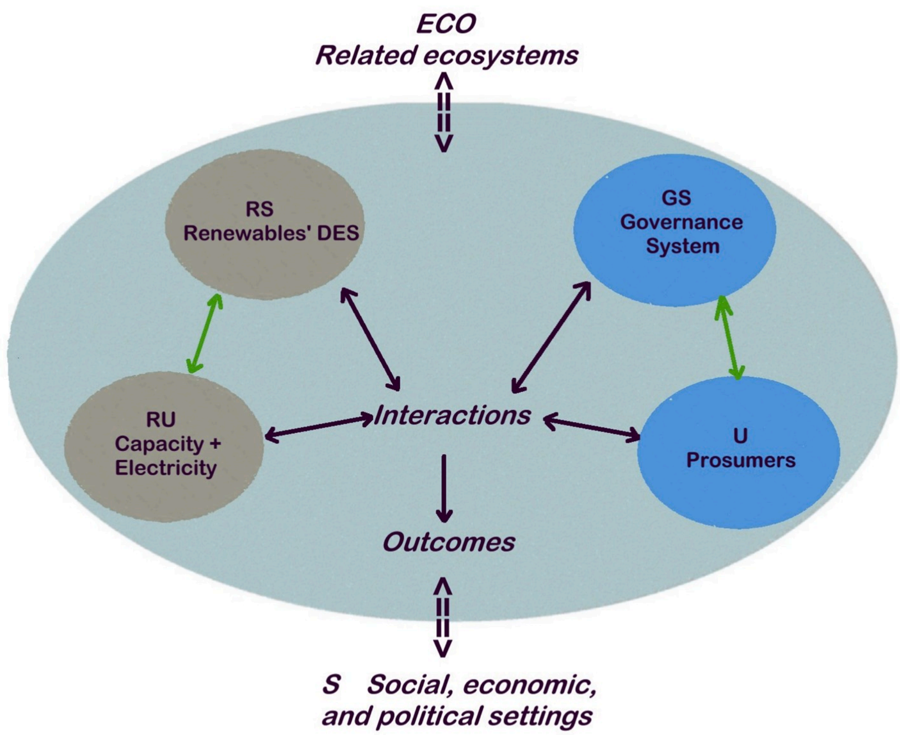

Fig. 2. Collectively managed DES, equivalent to the SES for sustainable use of a natural resource [55–57]. Explanation of subsystems and selection of 2nd-tier variables in Table 1.

4. Distributed energy systems

4.1. From DG to DES

Original definitions of 'distributed' focused on generation units located close to demand, and an anticipated escape from central grid control according to their 'purpose, the location, the mode of operation, the ownership, and the penetration of distributed generation' [1], p.196]. It implies enormous variety and differs greatly from the existing power supply model. The main objective of DES is furthering generation with renewables, but other benefits of DG have also been described. The interactions with *related ecosystems* (***ECO***, Fig. 2) are different, resulting in the alleviation of environmental problems more broadly [61].

Furthermore, additional advantages are enhanced affordability and reliability of the electricity supply (Fig. 3), i.e. 'energy security' [62], reliability and power quality, by increasing diversification of sources [63]. In remote areas where the low-voltage distribution grid is weak, there may also be an improvement of power supply quality by increasing the voltage in the network [64]. The latter, however, is increasingly problematic in less remote areas with large numbers of distributed generation feeding in. Voltages may rise too high [65,66] and distribution grids must be enhanced in response to such polluting factors when many producers separately feed-in [67]. These issues relate to aspects of *reliability* in power supply, commonly associated with 'energy not supplied', load curtailment, interruption frequency, and cost, and with *fairness* concerning the social distribution of these benefits [68].

A non-carbon transition requires that DG is restricted to generation with renewables, phasing out options such as combined heat-power or wind-diesel, but it must be extended to DES, highlighting adjacent infrastructures with a distributed character. These are important for enabling the integration of distributed generation renewables' systems within electric power systems. This integration is crucial for achieving the proclaimed benefits described above; however, much more fundamental research and practical experimentation is needed – both technical [70,71] as well as regarding regulations [72] and planning [73, 74].

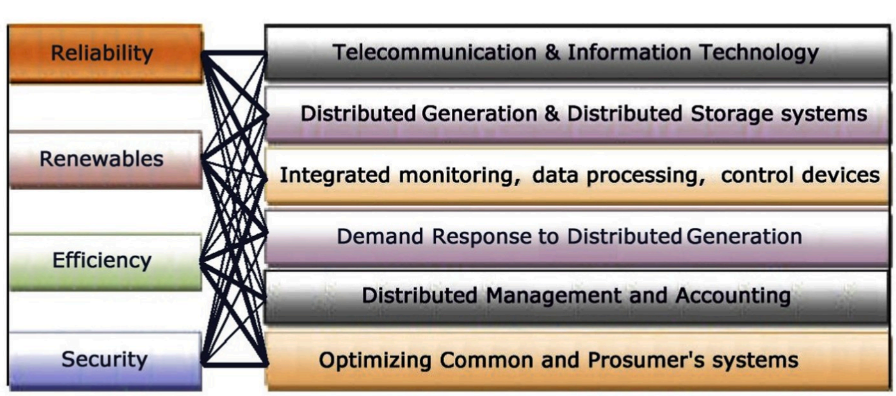

Fig. 3. Expected relationships between elements of grid-intelligence and quality of power supply (adapted from Ref. [69]).

The characteristics of distributed systems are at odds with the hierarchy and centralized design of the current grid, which already faces strong existential pressure, partly through the insertion, without system modifications, of variable RE power plants [32]. Besides the sunk costs invested in existing hardware of infrastructures, the rules that support the grid's strong centralist character are a key lock-in factor [75]. Energy companies and governments are poorly prepared to deal with DES [76], and are leaning heavily on hierarchical legislation and largely embody the lock-in challenges. The growing share of distributed systems requires a dismantling of the existing rules of the hierarchy of the centralized system, that often obstruct implementation. The move away from the hierarchy and standardized design of the centralized grid must be considered as the main object of the processes within the socio-political layer of SA2.1 (Fig. 1).

4.2. First characteristic: space

Renewable generation units are usually smaller than conventional (fossil fuel, nuclear) generation plants. A much larger number of units for generation is needed with a wide dispersion and variety (Table 1: ***RS9***). The generally low density [77] in space and land use – even for Photo-Voltaics (PV) [78] – is the primary scarcity factor, so in acceptance processes decisions on land use become crucial. The number of decisions is growing, and their character is changing. The trade-off between energy infrastructure and competing land uses becomes part of SA processes. Recognition of this issue in the literature is rapidly emerging [79,80], however, as usual primarily with a technocratic fix focusing on spatial configurations without realistic considerations about community and market acceptability. The complexity of decision making about how to make this space available – with the incredible variation in property rights as one the keys in CPR-management [81] – increases, because these innovative energy technologies have different spatial requirements and spatial effects [25].

Reduction of the requirements for scarce space and transmission losses can be achieved by reducing distances between generation and consumption. Generating power and balancing it with demand as close to storage and demand as possible is pivotal [82]. With the rapidly growing numbers of sites for DES infrastructures located close to demand, community acceptance becomes even more crucial than before. Communities are increasingly facing tough decisions about land use that combines DES infrastructure with other land uses. With the definitions of DG in mind [1,3], locations close to demand, direct connections to the distribution network, and DES infrastructures at the customer side of the meter are all factors that create high community interest in assigning space to such infrastructures.

4.3. Storage and demand response: balancing DES

Implementation of renewables in the STS of power supply requires the integration of various renewable sources [26]. Balancing varying supplies with demand is the ultimate requirement [83,84], which implies flexibility and buffering at the supply side [85] and flexibility and capacity to absorb at the demand side. Alterations of consumption patterns of end users – demand response (DR) – should respond to control signals from the system, possibly including dynamic prices [85–87]. Storage facilities and intelligent control devices become important integral components of DES and are crucial for the deployment of DG. Furthermore, the limitation of space requires storage of electric loads close to generation as well as consumption close to upload from storage.

The integration and balancing of all variable supply and demand loads and capacities of storage and transmission becomes highly complex, creating demand for intelligently controlled microgrids [30,88–90]. All equipment in the DES is connected to low and medium voltage networks – possibly even low-voltage DC [91,92] – and controlled by information and communications technology (Fig. 3).

The design and control of the grid at the consumption and distribution levels becomes a crucial element of the sustainable electricity sectors of the future. Whereas reliability of the current centralized grid is increasingly under pressure [32,68], many studies suggest that the introduction of intelligence in grids also enhances reliability and security (Fig. 3). The larger variety of sources in microgrids, their variety of geographic locations, and their enhanced flexibility, the better vulnerability is reduced and resilience increased [90,93].

4.4. Distributed beyond decentralized

The structure of the centralized grid and the existing operating practices do not benefit distributed systems. Large generation units have limited dispatch capacity, and, even though at the distribution side low voltage (LV) grids can be used for feed-in, the capacities of these LV-grids are only designed to satisfy consumption. Growing DG directly feeding into the distribution grid threatens to overload the LV-grid [94]. This concerns grid capacity as well as power quality (e.g., voltage increase). Continuous supply from hard to dispatch central generation may create overvoltage in cases of sudden increase in supply by renewables in LV-grids or by remote RE plants (e.g., offshore wind; solar plants). These voltage issues in the LV-grid may be resolved by responsive DES systems.

Reinforcing the LV-grid is expensive for DSOs (Distribution System Organizations). Possible mitigation of overvoltage may be possible with load absorption by local power consumption or local storage close to generation [95]; however, the main current DSO strategy is active power curtailment by cutting off renewables. Whereas conventional generation continues, this disconnection of DG leads to a loss of renewable energy and financial losses for DG producers, mostly prosumers with rooftop PV [68]. Hence, these practices represent a rapidly growing threat to market as well as community acceptance of DG. Balancing the grid by cutting off renewables typically is a consequence of managing the grid from a centralized perspective. The capacities of the distribution network fall short, particularly in low-populated areas where in the centralized paradigm grid capacities are small, because of low demand.

5. Example: co-production in a DES microgrid

The limited 'architectural innovation' [34] of the existing grid, with central power generation 'simply' replaced by renewables, is schematically pictured in Fig. 4A. Advanced Metering Devices (AMDs) measure consumption by different types of consumers, as well as the production of distributed power generating units. The latter are sited on consumers' private or common property (e.g., private or common rooftops), or on private, common, or public property (e.g., ground mounted PV, wind farms), which makes the process of getting these sites available is laborious and problematic in terms of SA. Demand Side Management (DSM) is applied to balance individual consumption with the centralized generation capacity of the public grid. As applied by energy companies or the DSO, DSM primarily serves the capacities of conventional centralized plants. This model also suffers from acceptance problems related to distrust [96,97]. With the decentralized location of centrally planned renewables' infrastructure – beside the community acceptance issues – many regulatory challenges emerge, such as equity problems resulting from unfair allocation of the electricity distribution costs (cross-subsidies), potential failure of DSO-operated remuneration systems, or sharp increases in distribution tariffs because of costs related to expanding transmission and distribution [98].

The DES alternative for the same spatial configuration is shown in Fig. 4B. Instead of generation units that are merely located in a decentralized spatial arrangement, the system follows the logic of distributed operation and management. The DES is not managed as part of the centralized power system but it is primarily balanced with and serves adjacent demand. Prosumers manage their own generating capacity together within one of the numerous variants of microgrids [4,30,99]

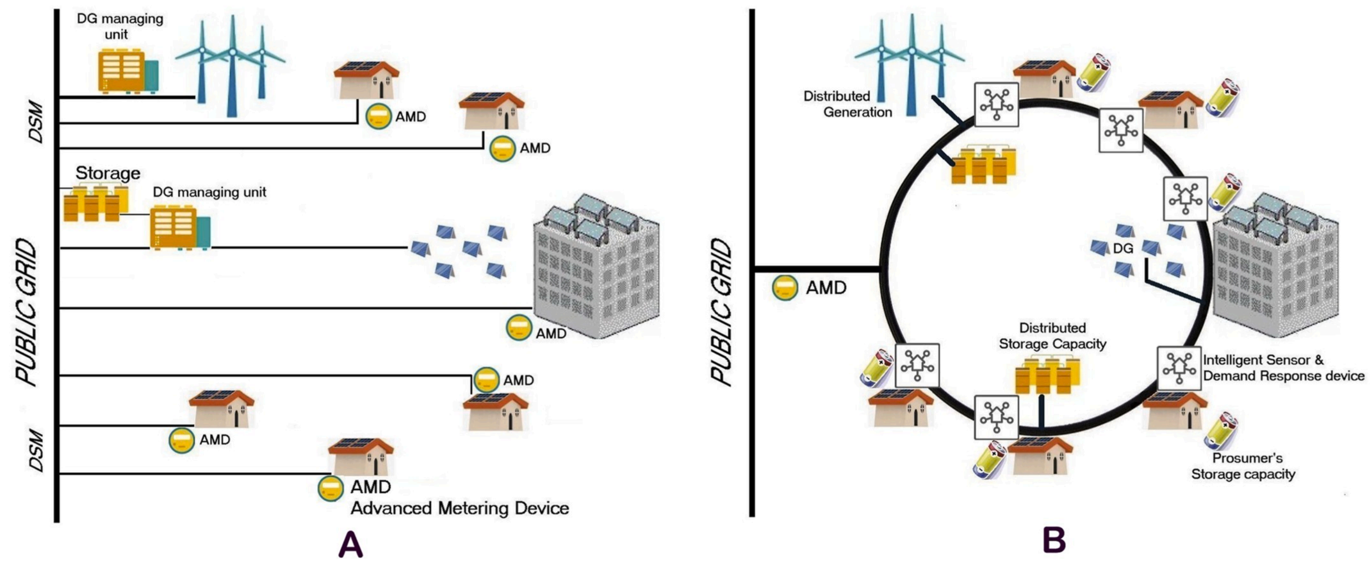

Fig. 4. **A**: Renewables located at decentralized sites in a centrally managed public grid (left). **B**: DES-controlled managed by co-producing prosumers, microgrid for the same community (right).

based on community co-production [25, 100]. Prosumers are primarily co-producing the infrastructures needed for the co-production of electricity. They do so with control over their own generation units and storage capacity, and they apply demand response [101] with monitoring and control systems. Typically, such DR concerns 'autonomous' demand management, a crucial condition for the emergence of intelligent grids [99,102]. The system-internal data are processed to optimize the balance between consumption and the power generated, stored, and reloaded within the systems of the microgrid (Fig. 3). The monitoring concerns the input of the following elements:

- different resources (wind, solar radiation, geo-thermal, etc.);
- available stored energy;
- available additional storage capacities;
- real-time demand;
- expected demand and options for flexibility [90].

These monitoring, data processors, and control devices are intelligent meters, however, expressly distinguished from the AMDs (Fig. 4A). Despite the latter currently being framed as 'smart meters' they hardly represent intelligence in the microgrid [103]. 'Smart meter' is a notoriously 'elastic term' [96], i.e. chiefly a policy claim within the current 'smart grid' discourse [104]. DR based on internal microgrid management together with individual and communal storage [105] is serving the feasibility of the prosumers' investments in co-produced DES, as the system maximizes the internal consumption of power generated within the system. Simultaneously the power exchange with the public grid is minimized, reducing the dependency on relatively expensive power from the public grid [106]. It helps to solve the capacity issue in the distribution grid. It reduces peak demand from as well as peak feed-in into the public grid, and it reduces the overvoltage issue.

6. Co-production of renewables: a common good

6.1. Peer-to-peer

The implementation of intelligent DES microgrids has enormous structural consequences for the power supply. DES microgrids require profoundly different organizational principles, as the collaboration at the level of the microgrid is pivotal. Although very different backgrounds exist in developing countries, for example in terms of socio-economic conditions and the absence of a pubic grid in large rural areas ('***S***' in Fig. 2) the concept of co-production within a common pool is still relevant [48,51]. One of the foundations of CPR-theory is the enormous variety of socio-ecological systems.

Examples of a microgrid community with hybrid DES currently only exists in practice at remote locations, mostly islands [107]. The configuration in Fig. 4B does not primarily represent a power supply network but also the social side of a collaborative social network [108] replacing the central, hegemonistic model. All studies modelling the DES microgrid situation take the starting point of 'grid-intelligence', usually framed as 'smart'. Balancing supplies and demand with shared infrastructures – collectively established, owned and managed generation, storage and distribution facilities – requires sophisticated monitoring and information processing capacities. Equally important, all these models assume *peer-to-peer* (P2P) delivery among prosumers [109,110], that "is able to reduce the energy exchange between the microgrid and the utility grid" [111], p, 11]. Balancing this within the microgrid first – without interference by the public grid manager – is crucial, because a large part of the P2P electricity is not directly distributed among the members, but stored in common storage first [105]. P2P becomes a key condition for the establishment and utilization of jointly installed and managed generation and storage infrastructures, in addition to collaborative balancing of consumptions within the microgrid [112,113]. This marks a radical paradigmatic and institutional change in the STS of power supply [30,42,111].

Empirical SA studies on the essential elements of the ***RS*** and ***RU*** components (Fig. 2) of intelligent DES microgrids are rare [30], but some explorations have already revealed that for user acceptance one key success factor is the abandonment of central control, with the control and management of the system radically shifting from the public grid to the users. Comparison of DSO-controlled and P2P models – similar to the models of Fig. 4A and B - indicates that prosumers strongly favour the P2P model, whereas consumers without generating capacity of their own prefer models that require low user effort or offer tariff incentives (business-as-usual, DSO-controlled) [114].

6.2. Common good

Internal P2P in a DES microgrid creates the fundamental condition for implementing reciprocity and sharing the efforts and benefits of co-production among the DES community members. Reciprocity is a necessary condition to establish 'trust' and create common economic value within the system (***RU4***, Table 1). Here we arrive at the basic institutional foundations of renewables' power supply by DES. It neither concerns the production of a commercial 'private good' nor the production of a monopolistic, usually state controlled, 'public good' (Table 2).

There is clearly *rivalry* in consuming the generated power. Any kWh used by a consumer within the common microgrid cannot be used by another. The current centralized grid is legally obliged to connect any consumer and to deliver, regardless of the consumption by others. But this public value of energy security is increasingly under stress [32]. With regards renewables, there is hardly exclusion in the access to the resource, which is defined as 'substractability' [115]. A prosumer catching the sun on her rooftop normally does not interfere with her neighbour, who does the same thing. Regularly harvesting renewables hardly prevents others to tap from the energy flow, though at another place. There is merely exclusiveness with regards the location of the faciities, as only the space required to place the infrastructure is scarce and subject to property regimes [115,116].

Co-production in DES concerns the creation of common value [,117], so renewables power supply becomes a 'common good' [52]]. Essentially, the common character comes to the fore in the much more prominent role of 'capacity' in DES rather than 'energy'. Whereas the latter is still mainly privately consumed, the capacity – of DG, of storage, of transmission, and even the capacity of short-term absorption – is commonly managed, often commonly used and owned or sited, and installed as a result of co-production.

The introduction of the concept of co-production of common goods was as follows: "individual consumers or groups of consumers … may contribute to the production of some of the goods and services they consume. In such cases they act as consumer-producers." [118, p.1001]. Co-production is the involvement of public service users in any phases of the design, management, delivery and/or evaluation of public services [119,120], and it has become a solid cornerstone in CPR theory [121, 122]. Co-production may combine elements of voluntary contribution and coercion [123]. Cooperation by the users may be voluntary, but as acceptance involves many players, also outside the DES, some coercive regulation on access to participation or land-use ('subtraction', Table 2) may be involved. Moreover, the locus of service production may be primarily directed at the provision of services to individual consumers; however, it may also concern involvement in the co-creation of a service system [124], and co-production becomes the production of 'common goods', replacing 'private' and 'public' goods [125]. Co-production is a way for citizens to play an active role in improving effectiveness and quality of services with public value [126].

All varieties of coproduction by cooperation of prosumers will exist in individual cases of DES. With the prevailing paradigmatic definition of distribution as a centralized monopolistic public good, and generation of power as a commercial good, the socio-political acceptance of the disappearing commodity character of electricity, and its transformation into a common good of renewables generation and storage capacity in DES, becomes an issue that should be analysed from a CPR perspective.

7. Socio-political acceptance

7.1. Prosumers: subsystem 'U'

In DES the prosumers constitute the subsystem 'users' ('***U***', Fig. 2) [56] p.421). Prominent variables (Table 1) include the *location* and the *number* of users. Because DES-microgrid is highly spatially defined, as a rule, these tend to run parallel to the area of the resource system ('***RS***'; Fig. 2). The social variables concern mainly *socio-economic attributes* of users, their patterns of *historical use* of electricity, and the *importance of electricity* for the users. These strongly depend upon the kind of users, who can be very diverse. In in addition to households, they may also include any other type of end user (farms, factories, schools, shops, offices, public agencies, etc.). User characteristics determine the available options for managing the STS, such as the existence of *leaders or entrepreneurs* among them, their *social capital*, the existence of *knowledge about the STS* and how the STS is viewed (e.g., *norms* and *mental models*).

Table 2
Typology of goods, distinguishing common from private, public and club goods. [115], Fig. 1.1].

	Exclusive Subtraction	Non-excludable
Rivalrous consumption	Private goods	Common goods
No rivalry in consumption	Club/toll goods	Public goods

7.2. Governance (sub)system

The governance system ('***GS***') is crucial for the transformation of the current centralized power supply system towards one based on distributed generation in intelligent microgrids. The literature is still rather ambiguous about the nature of how a DES microgrid should be characterized. The most informative studies have looked at DES as system-defined microgrids with P2P delivery, similar to lab studies that examine CPR theory [111,127,128]. These game theoretical lab experiments reveal the significance of co-operation in managing the system, but also of *co-producing the rules* running the DES. As in CPR research, they must be combined with empirical field studies in community energy projects [100].

Nevertheless, within the centralized system paradigm these studies continue to define the relations in the prosumer subsystem ('***U***') primarily as *market relations*, instead of institutional frameworks. Within this perspective, a DES-mircrogrid is viewed from outside as a 'local electricity market' (LEM) [129]. Each prosumer delivers a *private* good as a *commodity* to other consumers and consequently the adjacent regulation system is described primarily in market terms [112,129]. This business-as-usual approach restricts policy options to shape market mechanisms at the local level, but it also shows some benefits already. For example that options for efficient self-regulation of mutual accounting within microgrids are important for the feasibility of investments (financial, spatial, and social capital) in RE infrastructure. Moreover, it reveals options for reducing the microgrid's external peak demand [130], measured at the location of advanced metering device (AMD) in Fig. 4B.

For any market to work properly, a set of institutions – 'rules of the game' – are needed as a necessary precondition. Integrating prosumers by enabling them to establish a local energy market in which they mutually 'trade' their electricity – and even more importantly, empowering their capacities to produce and absorb electricity – requires fundamental institutional changes. Interventions or restrictions from outside create increase in transaction costs, so this fundamental change implies self-governance, a rapidly approaching option when *'distributed ledgers'* based on intelligent data management and 'permisionless' blockchain applications in microgrids are applied [131–133]. For any market, a set of institutions creating property rights, monitoring seller and consumer behaviour, and rules to enforce and maintain the systems are needed. These are complex, multilevel institutional arrangements, in which the LEM is nested. By framing peer-to-peer delivery (P2P) merely as an exchange of a private commodity, we continue to neglect essential preconditions for co-production by prosumers of the infrastructures as a common good (the resource system, '***RS***' and resource units, '***RU***' variables, Table 1). These variables are defining renewables as harvested and used in distributed energy systems as a common good, but they also are the most important objects of SA. They are relevant acceptance objects in processes in the '***GS***' as well as at the other levels of governance. These can be found in in the social, economic, and political settings for the DES microgrid ('***S***', in Fig. 2). Similarly, these can be found at the socio-political level of SA (Fig. 1).

In the design of the ***GS*** that facilitates distributed generation units and the installation and operation of associated DES infrastructures, we find the most significant elements that are objects of acceptance in SA of renewables. The variables identified in the STS framework and briefly described above are also highly relevant (in combination with '***U***', the prosumers) for the interconnections with the 'hardware' side, the subsystems '***RS***' and '***RU***'. All DES elements that constitute the necessary infrastructures (for power generation with renewables, storage, balancing production and consumption, applying the right spaces for installation) are facing many problems before they are implemented. These are all issues of SA. There may be *active resistance* among crucial actors (obstruction, resistance against initiatives, lack of cooperation among stakeholders, refusing crucial support). There may be *perceived low potential* (limited cognition, beliefs associated with paradigmatic, educational, and cultural lock-in). There may be *perceived low economic attractiveness* (also based on paradigmatic lock-in factors, or unfavourable market structures).

7.3. Institutional settings

Institutional frameworks profoundly influence all of the issues mentioned above to be considered in the creation of self-governing, adaptive STS for implementing distributed generation with renewables. These frameworks are often experienced as high-level policy risk for actors who would be willing to invest social capital or economic resources in DES. The risks are primarily determined by existing institutional conditions and by the perceived unpredictability in RE policies. The most effective instrument of the past, the guaranteed access for all to feed-in the public grid with fixed tariffs, ignored the grid capacity issue for as long as it was still possible. While these feed-in tariffs are increasingly being abandoned and replaced by complex subsidies with high transaction costs, RE installation rates are showing downward trends, despite being close to or already achieved grid parity in several markets [134]. The recently popular policy instrument – among policy makers and energy companies – of tendering or auctions in which cooperatives are forced to operate as market actors, is based on the idea of renewables single source power as a private commodity [135]. This is rapidly becoming obsolete as it does not recognize the necessity to integrate a single wind farm or a single PV-plant with the surrounding capacities: available renewable resources nearby, quantity and quality of electricity demand, transmission, storage options, and the capacity of community and market acceptance of these integrated options. Simple and standardized instruments like auctions are destructive for the emergence of more complex systems in which all these capacities are integrated. This integration will be different based on the varying socio-economic and ecological conditions at hand in all locations, precisely as foreseen in CPR-theory. Implementation practise in Germany shows how this recently implemented tender system turns out to disrupt community involvement and to create new obstacles for community acceptance for wind power [22].

The introduction of auctions is typical for the inconsistency of many regimes of renewable energy policy. There is widespread lack of confidence that existing policies can achieve effective regime change in a reliable way. In the past, long-term consistency has shown to be pivotal for pushing any renewables policy forward and preventing hard institutional failures [136,137]. Low acceptability, low economic viability, and perceived limited potential are often the result of institutional conditions, such as legal frames and organizations representing vested interests. These existing conditions are strong lock-in elements and they are associated with existing policy frames in the STS of power supply [8]. Although DES cannot be simply classified as decentralized but rather as distributed and, therefore, based on entirely different organizational principles [4], most obstructions for deployment are associated with the existing centralized and hierarchical power supply system, that discourages initiatives to establish DES. Current decision-making frameworks create investor reluctance, inflexible and counterproductive spatial decision-making, and they tend to reproduce hierarchic, uniform and inflexible policy frameworks (legislation, policies, culture, incumbent organizations, etc.).

CPR theory is primarily an institutional theory (section 3). What types of institutional arrangements would support the sustainable management of natural resources, in this case institutions that allow for and foster the establishment of STS that utilize renewables and replace the existing STS of a fossil fuel–based, centralized power supply?

A crucial institutional change concerns the establishment of regimes that allow for the emergence of governance systems (***GS***) based on self-governance and producing adaptive governance. Exploration shows that DSO-controlled microgrids are not attractive for prosumers [114]. Hence, for the potential prosumers who are willing to invest finances and space in all sorts of capacity in DES, high dependency and highly perceived external control are important barriers. These are considered as high-level risks as there is lack of trust that unanticipated and severe transaction costs [138] will not emerge. These transaction costs concern conditions to prosumers imposed by incumbents and authorities managing and regulating the centralized public grid.

At the level of socio-political acceptance of RE innovation, institutional changes that support the foundation of fruitful processes in the realms of market and community acceptance should establish conditions that support reciprocity and trust in subsystem '***U***' as well as trust in external ***SEP*** actors and settings (Fig. 2). Institutionalization is a product of the political efforts of actors, and the form that the resulting institution takes depends on "the relative power of the actors who support, oppose, or otherwise strive to influence it." [139], p.13]. Hence, for establishing institutional conditions that foster community and market acceptance of prosumer based DES (Fig. 1), generating a high level of socio-political acceptance is crucial. Following Ostrom in her recommendations, and in line with the state-of-the-art literature on co-production of public services, "governments should develop more flexible, service-specific and organization-specific approaches for promoting co-production, rather than looking for simple 'one size fits all' solutions to the challenges facing public service delivery, particularly of enduring welfare services." [140], p.183].

The institutionalized central hierarchical control of the current grids faces many challenges with the arrival of large, geographically dispersed DES capacities. Future power systems will be hybrid, based on the coexistence of some large-scale infrastructures and many distributed sources with wide spatial dispersion, large geographical variety, depending on the contribution to co-production and participation in DR systems [6]. The huge geographical variety of the systems and resources, the intensified land use competition on the scarcest 'space' co-production factor [25], and the interconnections with socio-economic regional variety [141] all ask for flexibilities, variety, and local knowledge that the current centralized, uniform, and hierarchical institutions do not offer.

8. Conclusion on socio-political acceptance of common DES

Governance of natural resources is a multi-level question [121], and environmental governance is best understood as the establishment, reaffirmation or change of institutions to resolve conflicts over environmental resources [142]. For the socio-political level SA-processes regarding distributed energy systems the fundamental question concerns the acceptance object [13,143], and institutionalized regime changes [29] are the key object of acceptance of the transformation towards integrated renewables in DES microgrids. Historical studies of institutions show that these are "always enduring legacies of political struggles" [144, p.388], and in renewable energy policy these struggles are conflicts about institutional elements of lock-ins [9].

The political character of long-term policies to orient transitions in large socio-technical systems concerns "the constant stream of decisions governments at all levels make regarding infrastructure renewal, and regulatory and fiscal frameworks, which can have a profound cumulative impact on societal subsystems." [145, p.337]. For renewables, technological substitution is insufficient for fostering innovation; instead, organizational 're-configuration' is required, for which a disruptive landscape is necessary [35].

Looking at renewables implemented in DES and the conceptual approach of an STS designed to harvest, manage and deliver the natural resource of renewable energy flows, what are the challenges to acceptance processes at the level of socio-political acceptance? Whereas most SA studies continue to focus on either single-resource projects within the paradigm of centralized power supply, or concern single actor, one-shot attitude studies [13], recent studies started to emphasize the crucial issue of socio-political acceptance [143,146].

The main objective of this review is to emphasize four keys as indispensable to shape comprehensive investigations of the intriguing questions of socio-political acceptance of new institutional regimes that could enable the full transformation of our power supply systems:

- the multi-level character [12,29];
- the polycentric nature [39,40];
- the social-technical system perspective of DES [13,25];
- and the potential of CPR theory and institutional analysis [56,147].

The following conclusions should be considered as hypothesis and starting points for future research.

C1: Renewable energy by means of distributed and integrated generation, storage, intelligent management, and demand response systems requires a shift towards prosumers, operating in systems based on co-production.

Integration is sorely needed to solve the pressing issue of limited grid capacities. More flexibility in the supply must be introduced by limiting inflexible central generation, by introducing storage and buffering capacities. Also needed is more flexible demand, by introducing flexible energy absorption: DR, distributed storage, and limiting distance between generation and consumption. Early studies on DR linked to renewables already revealed the necessity of high levels of community control, limited success with energy company control, and the relevance of energy absorbing capacities [148]. Community acceptance requires high levels of residential and prosumer control over their system [149,150], as well as over land use for infrastructures close to demand [19].

In the current centralized system, power supply is dominantly defined as a commodity and partially as a public good. Generated power is usually considered a 'private good', a commodity produced by private companies, whereas grid management is considered as a 'public good'. Electricity is provided by privatized actors – generation –, while the service of distribution is provided by utilities that are 'trading' companies – buying large scale and selling small scale – that can be either be private or publicly owned by regional or local authorities. For the distribution they are using the public grid that is usually operated by DSO monopolies operating under a mandate by the state. Depending upon the country's legislation, sometimes generating and distribution companies can be the same, or associated, or the DSO function is covered by the distribution company. In some cases, the centralization has been implemented to the extent that all three functions are performed by one company, under state control or ownership (e.g. EDF in France).

This framework is hardly open to any kind of good with a 'common' character [117] and does not support the emergence of 'citizen utilities' [151]. As prosumers [152] end-users want to generate and manage power by themselves as much as possible, so they have to do it in systems of co-operation, collectively storing it, with collectively established DES, on common and private space made available by cooperative actions.

Community energy, often labelled 'democratic' [153], is in fact more about the fundamental typecasting of electricity as 'good' or 'service' [154]. Co-production by prosumers of electricity as a *'common good'* becomes highly topical. The lock-in in power supply is not only embedded in sunk costs and vested interests, it is also discursive [155] and rooted in policy frames and belief systems [156]. The definition of power as a commodity to be produced and exploited commercially, and of distribution as a public, centralized and hierarchically driven public good, is politically cast in legal concrete. To reform this requires a paradigmatic change [157,158]. This change must take place at the level of socio-political acceptance [30,49,52,117]

C2: Electricity as an economic good or service must be redefined from power generation as a commercial private commodity and the grid as a public good towards distributed generation and DES as a common good.

CPR theory learns that similarly to social-ecological systems, all STS systems, geographically manifested at local or regional scales, show a high variety in DES (Table 1). At the socio-political level, the most important acceptance object is the move away from standardized, uniform, and hierarchically defined systems, towards those that allow for this high variety, complexity and autonomy. This regime change implies empowering consumers to become prosumers and to establish prosumer-consumer communities. High community acceptance, and high LEM-acceptance, requires a high level of self-governance, including cooperation at the same level with actors like local authorities, civil society organizations, and ESCO's of the prosumer's communities' own choice.

The other side of the coin is that trust obviously asks for disempowerment of currently powerful actors such as incumbents in the energy sector, and governments that refrain from mandatory legal regulation. Numerous are the studies showing the key issue of trust in renewables' deployment [159,160]. Studies on social-ecological systems, including human-made infrastructures, also suggest that the relationship between the users of the resource and the public infrastructure providers is the most important element in the institutional framework that defines the robustness of the system [161].

A power supply that substantially relies on interconnected intelligent DES, requires a shift from centralized hegemonistic models towards polycentricity. The central actors are no longer the current ones that exercise hierarchical power, but the ones who are well-situated and are able to facilitate collective action in establishing the DES. The organizational principles should be understood in terms of network theory [108]. As Ostrom [59] emphasizes, the role of national and international government actors remains important but is fundamentally transformed. The prime issue is to support and maintain the non-rivalry of the resource (Table 2), for example by focusing on justice issues such as access for all of the DES-system. Restrictions or regulations creating high transaction costs for harvesting renewable energy by prosumers should be avoided and existing ones abandoned. Most of these concern firts forcibly defining distributed generated power as a commodity, and then treating it as such, e.g. by taxing the electricity within the distributed systems. However, it is not a commodity as the prime objective is power generation for direct consumption, for P2P delivery to others within the microgrid, or for common storage within the DES [162,163]. Government regulation should focus on real public values, such as safety standards for devices, on maintaining justice in processes and distributive outcomes [142], and safeguarding ecosystem impact [164,165]. For the state and other tiers of government, the object of acceptance is to institutionalize conditions that create optimal opportunities for self-governance in DES communities [128]; hence.

- to define the boundaries of the resource itself and the group of users;
- to adapt the rules concerning the use and provision to local circumstances (Who is entitled to what? Who contributes what?);
- to allow co-producers to be involved in and empowered in decision-making processes on land-uses for infrastructure, and system design;
- to develop a legal and social infrastructure helpful for resolving conflicts between the actors involved.

C3: A fundamental characteristic in common prosumer-base systems is the application of P2P, peer-to-peer deliverance.

This is a crucial precondition for opening up any system design, socially as well as physically, for co-production of electricity. As within

DES, the generated power by one consumer can be absorbed directly, delivered to a neighbouring user, or to a private or commonly owned storage facility. Most likely the electricity becomes part of a common pool, an amount of power that is directed towards other consumers in the DES, to private or commonly owned storage, or the remainder to the public grid, regulated as an LEM [166,167]. Optimizing these flows and, equally important, optimized use of the installed generation and storage capacities is crucial for the feasibility of all sustained prosumer investments.

This P2P issue [166–168] is entangled with the common good character, and so is the issue of property rights resulting from the investments of the DES and other participating stakeholders [81]. With regards these, for offered spaces for infrastructure and all elements of these infrastructures, a wide variety of 'bundles of rights' [81] exists, so the outcome of contributions from all sides is a complex mixture. All infrastructure may be established with different investments from all sides: finances, space (rooftops, gardens, facades, fields, cellars, attics, garages) and social capital (time, efforts, knowledge, skills). Hence, for community and market acceptance any legal or other institutional framework that obstructs P2P or investments of all kind, will create transaction costs and enhanced perceived policy risks associated with current inconsistent energy policy regimes [114,130]. The governance system of the DES also places strong requirements for empowerment and rights to decide about land use and use of other spaces for establishing the DES.

C4: Space is the prime scarcity factor in establishing renewables and their supporting infrastructures; therefore, co-production also should empower DES communities in land use decision-making.

Strong commitment of all affected actors is needed: those with a stake in land use, but also anyone with substantial place attachment such as members of the broader community [25]. This is a complex undertaking and best practice experiences are limited, because both land use and ownership of infrastructural elements in the DES are ruled by different property rights regimes. The current systems of spatial planning seem largely inconsistent with the requirements of self-governance and empowerment over spatial investments of prosumers in their DES. Again, the key question is how to redefine the centralization tendencies in spatial planning towards systems in which co-producers in DES microgrids become entitled to decide upon their own distributed infrastructures, which includes the deployment on their own and surrounding spaces.

Declaration of competing interest

The author declares to have no conflict of interests.

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