Renewables: common pool natural resources – distributed generation in intelligent grids

Maarten Wolsink *

"Breaking the Rules – Energy Transitions as Social Innovations"
conference June 14th-15th, 2018 at WZB Berlin Social Science Center.

Keynote for the conference

* University of Amsterdam
Department of Geography, Planning and International Development Studies

Abstract

The current trend in our power supply system is to shift power generation towards much smaller energy conversion units: DGRS – Distributed Generation using Renewable Sources. Traditional power plants are large centralised units, primarily fuelled by coal and oil, natural gas, nuclear fission and large hydro-power stations. These are deeply institutionalized socio-technical systems (STS), but the future perspective of this STS needs upgrading, as current systems are run by "big unwieldy corporate machines" whose change is "characterized by recalcitrance and torpor" (Bakke, 2016,p.xx). The adjacent consequences of the emergence of DGRS requires far reaching re-organization of the STS, that implies significant institutional changes moving away from centralized and hierarchical management (Wolsink, 2018).

DG is based on a network of multiple, smaller generating units and other infrastructure – storage, transmission – situated close to energy consumers, integrated in *microgrids* that together constitute an *intelligent grid* (Gui et al. 2018; Wolsink 2012; von Wirth et al., 2018). The essence of DG in microgrids also implies the recognition of the significance of cooperating actors – prosumers – to establish power generating capacity integrated in these microgrids. An essential building block of intelligent grids is adaptation of demand patterns by all sorts of demand response (Siano, 2014). Calculated technical potentials for demand response may be interesting, but eventually the rate of acceptance of such systems becomes the key issue for realization of adapted demand patterns. Centrally led Demand Side Management schemes are known to be unpopular among customers (Darby, McKenna, 2012), but demand response within cooperation

networks of prosumers aiming at enhancing the utilization of their own DG seem to be more promising.

The multi-disciplinary theory applicable to this new STS system, aimed at sustainable use of the natural resource of renewables', is the institutional theory developed for the proper management of social-ecological systems, common pool resource theory (Ostrom, 2009). The concept of 'coproduction' means that citizens can play an active role in producing public goods and services of consequence to them (Ostrom, 1996). Recently, CPR theory has been recognized as a fruitful approach for studying social-technical systems for the provision of power with DG, which is literally co-production of electricity. It is also co-production on planning and decision-making on DG and other intelligent grid infrastructures, as within a microgrid the partner-prosumers have their input in terms of asset like generation capacity, space for infrastructure, and storage capacity, and this input may be individual as well as collective when these assets are installed by co-operation and collectively managed. A major institutional change needed for this, is that generated power or re-loaded power from storage facilities can be peer-to-peer consumed by others in the microgrid. These factors may be considered a manifestation of the 'sharing economy' (Martin, 2016). Peer-to-peer delivery is one of the elements fully running counter to the centralized design of the current power supply system. The producer-customer paradigm is institutionalized in legislation, in design of tariffs, and in hardware (location, design and ownership of meters), and as a result in dominant – even locked-in – ways of thinking. Besides the rapid emergence of DG technologies – PV reaching the level of 'grid-parity', electric vehicles, supercapacitors, batteries (Wolsink, 2018) – within the domain of ICT, there are also rapidly emerging technologies supporting the intelligent self-governance of the energy flows, generation, storage and transmission capacities – sensors, artificial intelligence, blockchain etc. As another major example the consequences of these developments for yet another institution that is part of the lock-in in our current power supply systems, taxing, will be discussed.

Renewables:
Common Pool Natural Resources –
Distributed Generation in Intelligent Grids

"Breaking the Rules – Energy Transitions as Social Innovations"
keynote 14 June 2018
to the conference June 14th-15th, 2018
at WZB Berlin Social Science Center, Berlin (D)

Maarten Wolsink
Dep. of Geography, Planning
and International Development Studies
University of Amsterdam

Starting points

- Conference slogan tells us: transforming energy systems: **'Social Innovations'**
- **'Breaking the Rules'**
- Indeed, this talk is about the proces of social acceptance of **"institutional change"**
- Institutions are (definition)
  … *behavioural patterns* as determined by societal rules…
  "the rules of the game in society"
  North D, 1990. *Institutions, Institutional Change and Econonmic Performance.* Cambridge University Press.
- Renewables are natural resources. Common Pool Resources theory on sustainable resources use (Ostrom) is also an institution

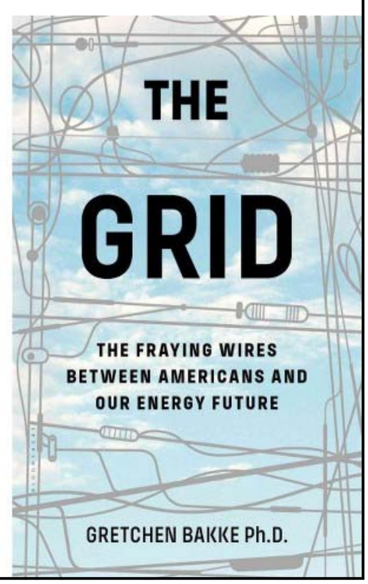
Starting points

- Power supply system(s) is an STS
  Social-Technical System
  A system be made up of scientific and technological, as well as socio-economic and organizational components.
- Transforming this STS into renewables based, zero-carbon is ***Innovation***…. including 'creative destruction'
- Innovation – definition –
  A change of ***ideas***, that becomes manifest in ***products, processes,*** or ***organizations***, that are applied successfully in practice.
- Key innovation is:
  move the STS away centralized design & hierarchical and centralized management

A 'must read' on the need to innovate power grid (book on North America)

❖ The electricity grid is
- a machine
- an infrastructure
- a cultural artifact
- a set of business practices
- and an 'ecology'………

❖ …..designed for the exact opposite of 21st-century needs



Innovation theory on current STS

Famous lock-in example: “Clio and the economics of qwerty” David, AmEconRev, 1985

- Institutional “lock-in” Unruh, 2000 EnergPol ‘carbon lock-in’
- Existing configuration energy sector emerged in history (“path dependency”)
- To serve certain objectives (rational, *but also political*)
- STS cross-linked with sectors like industry, land use, transportation, communication…(also: path dependency)
- Current system → does not serve new objectives
  → barriers; resisting vested interests → inertia
- New elements of STS are not accepted easily…….
  → social acceptance turns as the key to realize RE potentials,
  → particularly structural social elements of the STS: institutions

Moving away from Centralization and Hierarchy

- Current STS:
  - generation in central power plants
  - distribution via centralized infrastructure
  - hierarchical and uniform regulation and management
  - centralized accounting: metering and tariffs
- Move away: towards inreasing DGRS
  - Distributed Generation, rapid emergence of prosumers
  - rapid increase of variety (infrastructure, and organization)
  - Polycentricty in governance and management
  - distributed accounting:

  - distributed (intelligent) metering; peer-to-peer delivery; variable and dynamic tariffs; variable and distributed ledgers

Definition

Ackermann et al 2001

❖ **Distributed Generation**
(more broadly: Distributed Energy Resources)

is an electric power source (or other electric resources)

- connected directly to the distribution network

- or on the customer site of the meter.

- Geograhically dispersed
- Numerous locations
- Huge variety

Variety: huge diversity in Distributed Generation: with implications for co-production and spatial requirements

sample Ackermann et al 2001; table Wolsink LandscRes 2018

Table 1. Distributed Generation, options for co-production, spatial claims and landscape-issues (sources: see acknowledgement).

Type of infrastructure	Size (capacity)	Relevance for co-production/participation	Spatial claims (amount / type)	Landscape *relevance* / type
Combustion turbine CHP (pref. biomass/biofuel)	1–250MW	Single owner / co-operative / or central	*Small* / Spot	*Low* Visual impact; Ecology crop cult.
Micro-CHP (combustion; pref. biofuel)	35 kW–1MW	Single owner / co-operative /	*Moderate* / Spots; Larger numbers	*Low* Visual impact; Ecology crop cult.
Biomass, e.g. gasification	100 kW–20MW	Co-operative / Possibly single owner	*Large* (crops) / Areas for growing crops	*High* Ecology crop cultivation
Stirling engine (micro CHP; pref. biofuel)	2–10kW	Single owner	*None*	*None* Ecology: fuel
Small hydro	1–100MW	Possibly co-operative/ shareholders	*Substantial* basin	*Substantial* Ecology river
Micro hydro	25 kW–1MW	Co-operative / Single owner	*Small*	*Low* Ecology stream
Wind farm onshore / near shore	5-500MW	Possibly co-operative / shareholder	*Moderate* / Area combined use	*High* Visual impact /
Off-shore wind farm	20-1000MW	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	1-500MW	Central; possibly co-operative or shareholder	*Large* / Large areas; hard to combine	*High* / Visual impact / Ecology soil
Solar central thermal receiver (mirror based)	1–10MW	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–250kW	Single owner / co-operative	*Small* Spot; indoor	*None*
Geothermal	5–100MW	Single owner / co-operative / shareholder	*Moderate* Spot; track (pipe)	*Low* / Visual impact
Marine energy: Waves	500kW-50MW	Co-operative / shareholder	*Moderate* Island; coastal	*Moderate* Ecology shallows
Tidal flows	200 kW–250MW	Co-operative / shareholder	*Moderate* Estuary / bay	*Substantial* Ecology estuaries
Wind turbine off-shore/near shore	200 Watt–5MW	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-5MW	Co-operative / shareholder	*Moderate* Mainly estuary	*Substantial* Ecology estuaries
Saline gradient: Osmotic Pressure	4 kW-50MW	Co-operative / shareholder	*Moderate* Mainly estuary	*Substantial* Ecology estuaries
Seawater cooling (saving power for Airco)	4MW-50MW	Co-operative / shareholder	*Moderate* Coastal / Islands	*Low* Deep coastal water
Ocean Thermal Energy conversion	50kW-50MW	Co-operative / shareholder	*Small* Islands	*Low* Ecology

Micro hydro	25 kW–1MW	Co-operative / Single owner	*Small*	*Low* Ecology stream
Wind farm onshore / near shore	5-500MW	Possibly co-operative / shareholder	*Moderate* / Area combined use	*High* Visual impact /
Off-shore wind farm	20-1000MW	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	1-500MW	Central; possibly co-operative or shareholder	*Large* / Large areas; hard to combine	*High* / Visual impact / Ecology soil
Solar central thermal receiver (mirror based)	1–10MW	Central; possibly co-operative or shareholders	*Large* / Large area; hard to combine	*Substantial* / Visu 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–250kW	Single owner / co-operative	*Small* Spot; indoor	*None*
Geothermal	5–100MW	Single owner / co-operative / shareholder	*Moderate* Spot; track (pipe)	*Low* / Visual impact
Marine energy: Waves	500kW-50MW	Co-operative / shareholder	*Moderate* Island; coastal	*Moderate* Ecology shallows
Tidal flows	200 kW–250MW	Co-operative / shareholder	*Moderate* Estuary / bay	*Substantial* Ecology estuaries

Distributed Energy Resources: also storage and transmission options

table: Wolsink, 2018

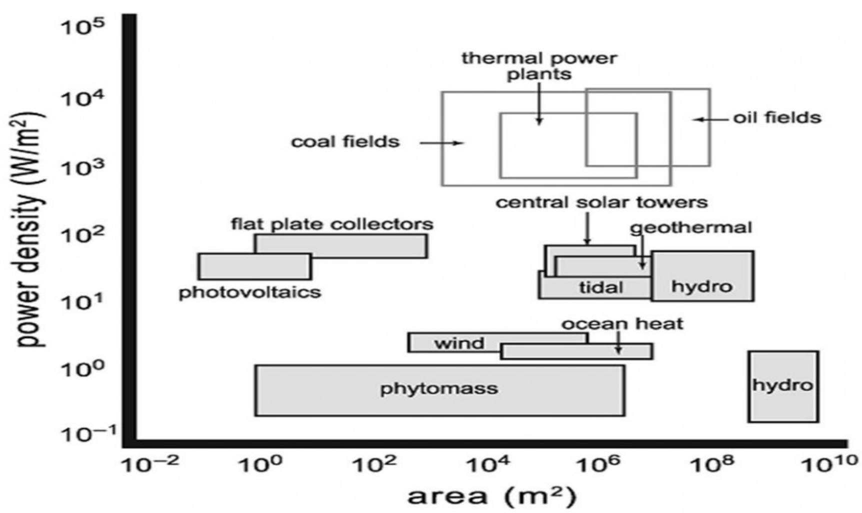
Type of infrastructure	Size (capacity)	Relevance for co-production and participation	Spatial claims (amount / type)	Landscape *relevance* / type
Distributed Storage				
Heat storage (electric boilers)	1-4kW	Single owner	*None* indoor	*None*
Heat stored buildings (solar, electric heat pumps)	10-500kW	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 cell hydrogen storage	50-1kW	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*		
Neighborhood Water systems	10kW-1000kW	Co-operative / public / shareholder	*Moderate* Level in basins / groundwater level	*Low* ecology groundwater
Pumped hydro (high altitude water basins)	1MW-1000MW	Centralized	*Large* Land use change as with large hydro	*High* Ecology; abandon functions like Agriculture
Desalinization: reservoirs	10kW-50 MW	Co-operative / shareholder / public	*Moderate* plant; basin	*Low* visual
Transmission of	*RES generated*	*power*		
HVAC Transmission	10-150kV	Public / private /centralized	*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)	20-100V	Co-operative / household	*Small* Indoor / Undergound	*None*
Low voltage grid (AC)	220V-25kV	Public / co-operative	*Small* Indoor / Underground	*Low* Visual in case of in open air

Type of infrastructure	Size (capacity)	Relevance for co-production and participation	Spatial claims (amount / type)	Landscape *relevance* / type
Distributed Storage				
Heat storage (electric boilers)	1-4kW	Single owner	*None* indoor	*None*
Heat stored buildings (solar, electric heat pumps)	10-500kW	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 cell hydrogen storage	50-1kW	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*		
Neighborhood Water	10kW-1000kW	Co-operative / public /	*Moderate*	*Low*

Renewable Energy is abundant

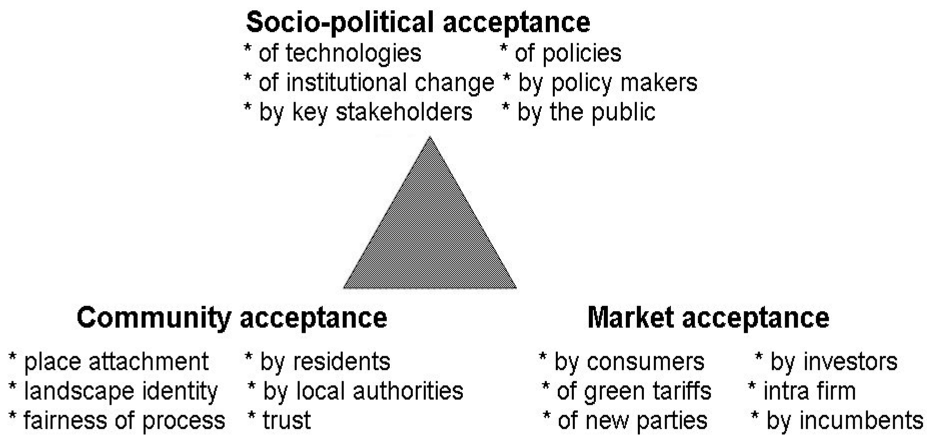
Scarcity is required space

Energy-density (energy/area) Smil, 2010

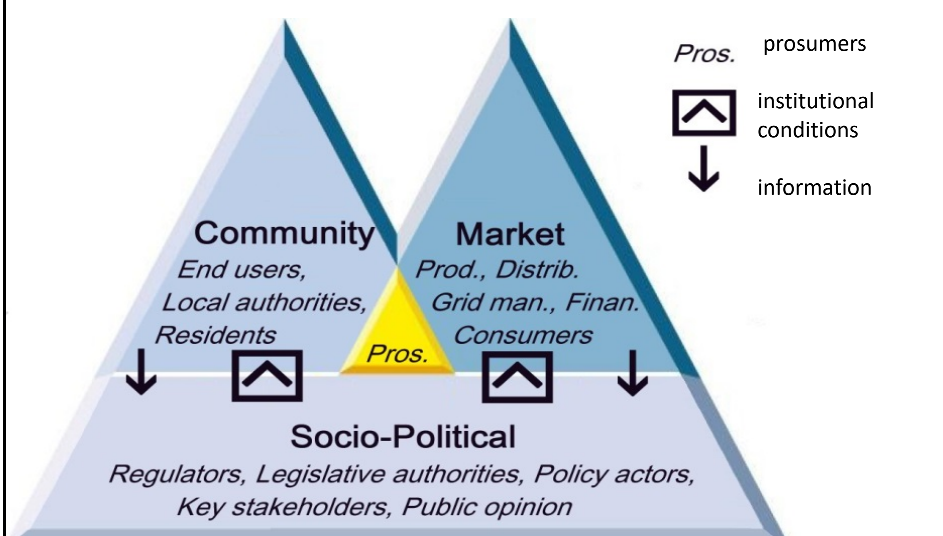


Decision about all elements – social design (economic, political, cultural), technological design, decisions about space for infrastructures teaken in processes of Social Acceptance

(Original concept: Wüstenhagen et al. 2007)

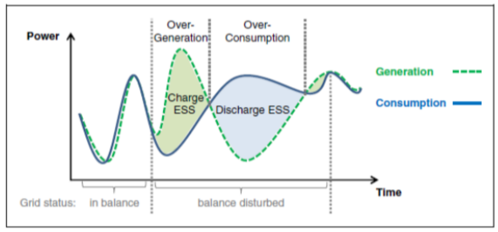


Social Acceptance, advanced:
multi-layered processes



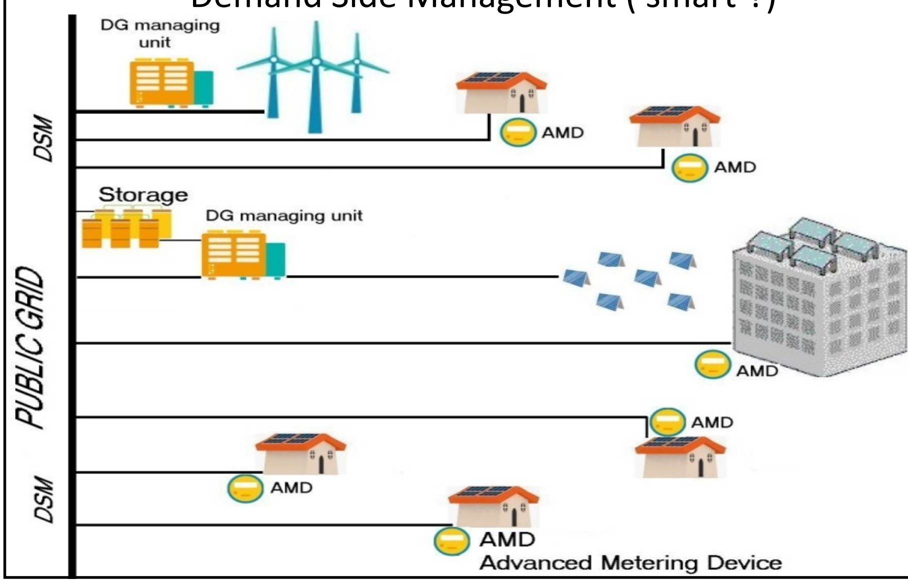
Huge spatial requirements (need reduction distance prod.-cons.)
Varying in supply patterns (need adapted demand patterns)
Huge geographical variety STSs (abolishment uniformity)

- Different patterns of variable supply (ecology)
- Optimization supply and demand: needs (micro-) optimization

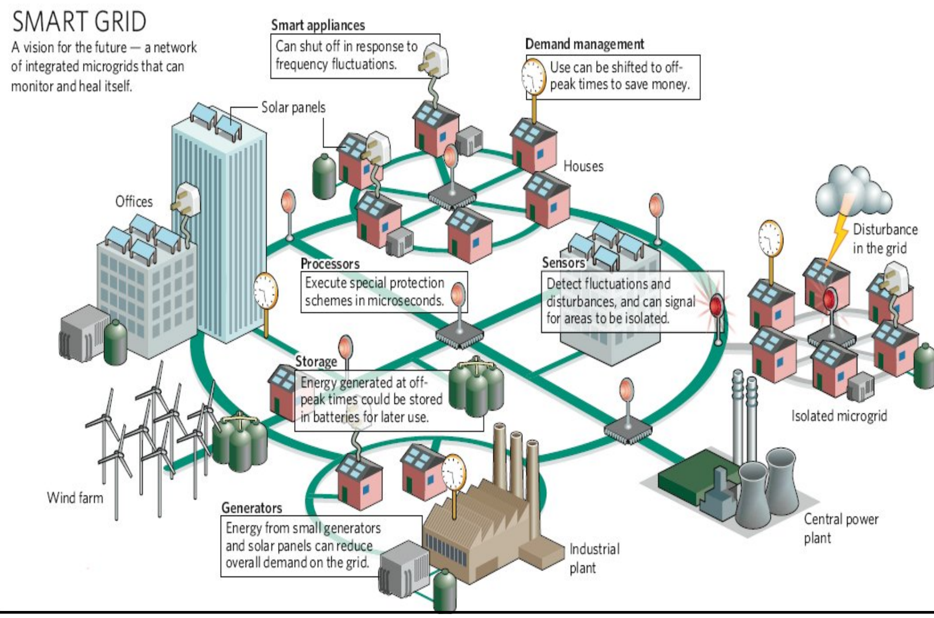


- Development of (local) micro-grids,
  - several 'prosumers' in a 'community'
  - load-control *(supporting DG)*
  - including local storage
- Intelligent metering and regulation devices
  (supporting 'prosumers' and 'micro-grid community')

Dominant discourse:
Centralized Grid, RES replacing fossil, central storage, Demand Side Management ('smart'?)



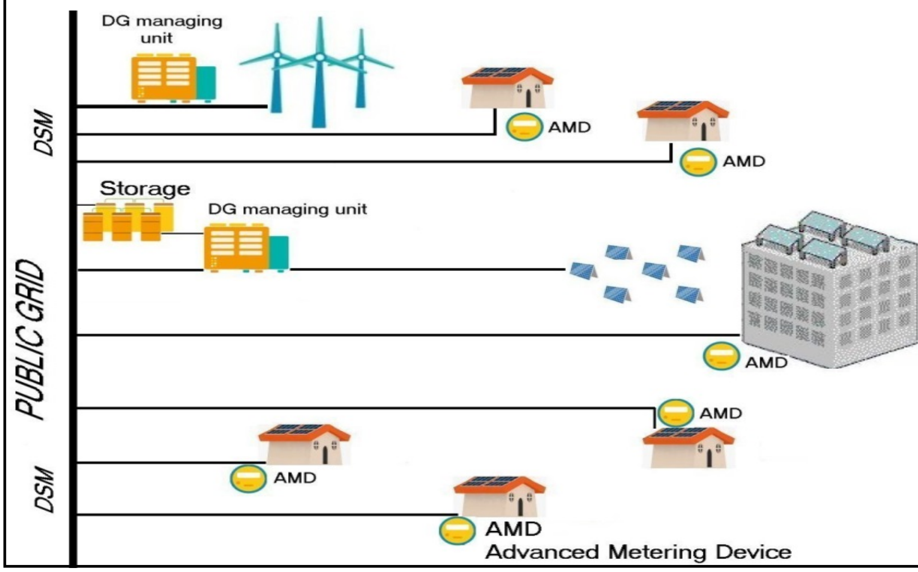
Alternative: the intelligent grid Marris, 2008



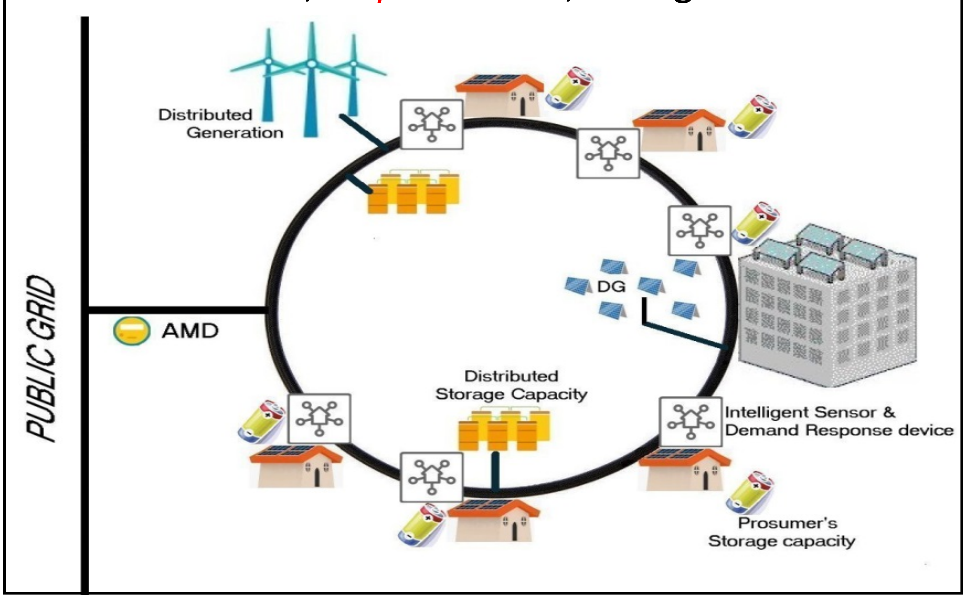
Strong pressure on the power grid: towards an Intelligent Grid

- "Power grid consisting of a network of integrated micro-grids that can monitor and heal itself"
  Marris, 2008. Nature 454: 570-573
- → Fundamental question:
  *Which **institutional changes** needed to establish those micro-grids with renewable DG as much as possible?*
- Who will invest?
  Who is in control?
  Over what?
  vonWirth et al, 2018; Gui et al. 2017; Wolsink 2012
- Ownership and control is about:
  - all assets of the infrastructure
  - decisions about space
  - collecting and use of data

Centralized Grid connecting RES, storage,
Demand Side Management



Intelligent Microgrid-community
DG, *co-production*, storage



= co-produced and individual Distributed Storage capacity

Parra et al, 2017

- Batteries (Li-ion; NiCd; Ni-Metal hydrate …)
  - including V2G (electric vehicles)
  - developing: NaS
- Thermal (devices, underground…)
- Developing: Supercapacitors - high (dis-)charge capacity
- Developing: fuelcells; hydrogen
- Possible options:
  - Flywheels (option for short term network stability)
  - Compressed air
  - Superconducting Magnetic Energy Storage (short term, micro SMES for internal microgrid network stability)

Another way to define social acceptance – in terms of Common Pool Resources theory

Social acceptance of renewables' innovation is the process of organizing 'co-production' Ostrom, 1996; Wolsink 2018

- in establising infrastructure
  (investing, required space, sharing data)
- of electricity

- The inclination to cooperate in varying STSs (as compared to SES's, Social Ecological Systems)
- among multi-level actors (community, market, policy making)
- to establish, maintain, operate
- socio-technical systems of power supply and and shared use
- based on natural resources of renewables

Fundamental features

- Social-Ecological Systems exist with **huge variety** (→ essentially geographical variety)
- Complex, almost never simple; natural variety *and* social variety (pluralism, polycentrism)
- **Internal variety is good** (supports resilience)
- **Complexity is good**
- All efforts to simplify: “not a good idea”

  https://www.youtube.com/watch?v=Qr5Q3VvpI7w#t=0.115416
- These notions run counter to common sense views, …… widely held among policy analists, governments, and technocratics more broadly

Ostrom,1999. “Coping with tragedies of the commons”

Am Polit Sci Review 2 493-535

"Contemporary policy analysis of the governance of common-pool resources is based on three core assumptions:

(*a*) resource users are norm-free maximizers of immediate gains, ……

(*b*) designing rules to change incentives of participants is a relatively simple analytical task

(*c*) organization itself requires central direction”

“……… all three assumptions are a poor foundation for policy analysis.“

Institutional settings should foster, create, and maintain…

- **Trust**
  → crucial characteristics are:

➢ *Self governance*: within framework let users organize themselves

➢ *Adaptive governance*: system should be flexible, resilient to sudden, external changes

➢ *Polycentric* governance: decisions not taken in one centre, but at many different places, different arenas Ostrom, 2010, p551

➢ *Multi-level governance*: actors part of SES operate on different scale levels, also different governance levels (**scale ≠ hierarchy**)

Ostrom – General framework - 4 subsystems Ostrom, 2009

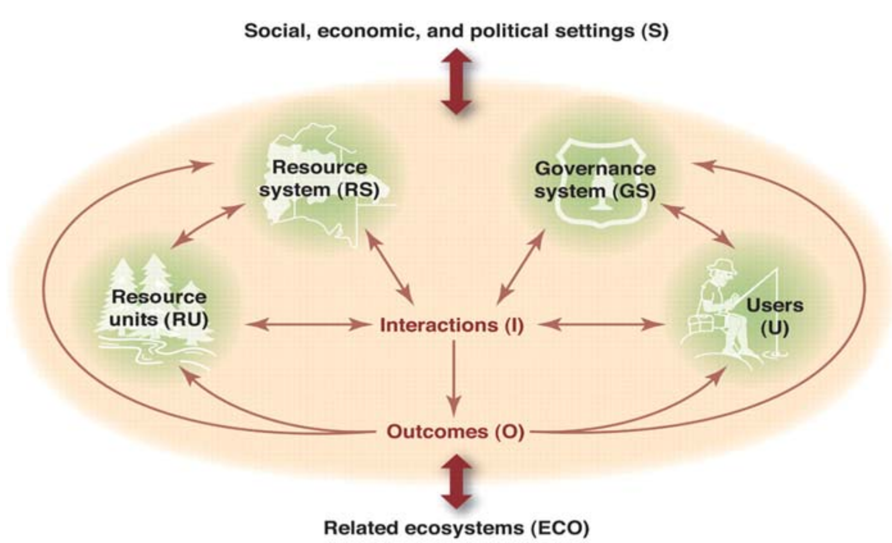


Table 1. Second-tier variables in framework for analyzing an SES

Social, Economic, and Political Settings (S)
S1- Economic development. S2- Demographic trends. S3- Political stability.
S4- Government settlement policies. S5- Market incentives. S6- Media organization.

Resource System (RS)	Governance System (GS)
RS1- Sector (e.g., water, forests, pasture, fish)	GS1- Government organizations
RS2- Clarity of system boundaries	GS2- Non-government organizations
RS3- Size of resource system	GS3- Network structure
RS4- Human-constructed facilities	GS4- Property-rights systems
RS5- Productivity of system	GS5- Operational rules
RS6- Equilibrium properties	GS6- Collective-choice rules
RS7- Predictability of system dynamics	GS7- Constitutional rules
RS8- Storage characteristics	GS8- Monitoring & sanctioning processes
RS9- Location	
Resource Units (RU)	**Users (U)**
RU1- Resource unit mobility	U1- Number of users
RU2- Growth or replacement rate	U2- Socioeconomic attributes of users
RU3- Interaction among resource units	U3- History of use
RU4- Economic value	U4- Location
RU5- Size	U5- Leadership/entrepreneurship
RU6- Distinctive markings	U6- Norms/social capital
RU7- Spatial & temporal distribution	U7- Knowledge of SES/mental models
	U8- Dependence on resource
	U9- Technology used
Interactions (I) →	**Outcomes (O)**
I1- Harvesting levels of diverse users	O1- Social performance measures (e.g., efficiency, equity, accountability)
I2- Information sharing among users	O2- Ecological performance measures (e.g., overharvested, resilience, diversity)
I3- Deliberation processes	O3- Externalities to other SESs
I4- Conflicts among users	
I5- Investment activities	
I6- Lobbying activities	

Examples RS (Resource system) variables RU (resource units) variables

RS2 System boundaries → boundaries of microgrid

RS4 Human constructed facilities → all infrastructure

RS8 Storage: also human constructed

RU4 Economic value → peer-to-peer deliverance

RU7 Spatial and temporal distribution → storage, demand response

ExamplesVariables defined in the Governance System

GS3 Network structure (network organization Martin, 2014 instead of company)

GS4 Property-rights systems

GS5 Operational rules → DR system, distributed accounting

.....

GS8 Monitoring and sanctioning processes Advanced sensors and DR device (intelligent meter)

Variables defined in ’ U’ (Users) and ‘I’ (Interactions)

U2 Socioeconomic attributes of users
U6 Norms/social capital

U9 Technology used

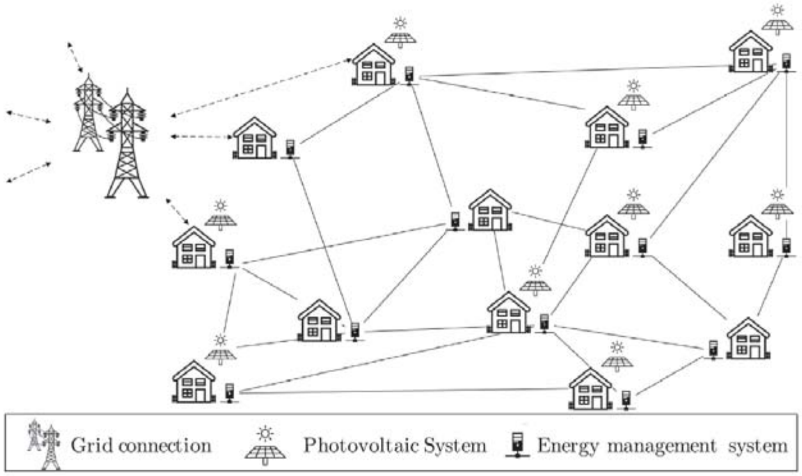
I1 Harvesting levels diverse users

I2 Information sharing among users ict within the intelligent microgrid

O1 Social perfomance measures (efficiency, accountability, equity)

Scheme microgrid based on DG with peer-to-peer delivery

Mengelkamp et al Appl Energ 2018



First DG solar microgrid Brooklyn, NY sept, 2017

- DG with peer-to-peer transactions
- Cooperating prosumers
- Operation based on sensors and processors
- Mutual accounting based on internally collected and owned data (→ distributed ledgers)
- 'Trust' institutionalized by blockchain technology; recent option, further research needed

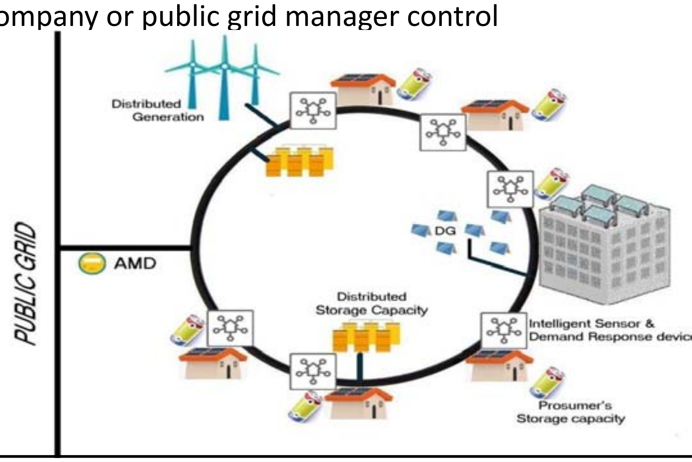
(a) The BMG connects participants from three distribution grids: the Borough Hall (red), the Park Slope (green), and the Bay Ridge (purple) network.

Example of institutional conflict:
Incumbent/vested interest government/state (part of lock-in) in current STS

Intelligent meters (sensor + demand response device)

▪counting blockchain 'credit' based on Artificial Intelligence
→ no energy company or public grid manager control

- Can energy-flows still be taxed?
- Not without impeding DG and DStorage



Thank you

references

Ackermann, T., Andersson, G., Söder, L. (2001). Distributed generation: a definition1. *Electric Power Systems Research*, *57*(3), 195-204.

Bakke, G. (2016) The Grid – The fraying wires between Americans and our energy future. New York: Bloomsbury.

Darby, S. J., McKenna, E. (2012). Social implications of residential demand response in cool temperate climates. *Energy Policy*, 49, 759-769.

David, P. A. (1985). Clio and the Economics of QWERTY. *The American Economic Review*, 75(2), 332-337.

Gui, E.M., Diesendorf, M., McGill, I. (2017) Distributed energy infrastructure paradigm: Community microgrids in a new institutional economics context. *Renewable Sustainable Energy Reviews,* 72, 1355–1365.

Marris E (2008) Upgrading the grid. *Nature* 454: 570-573

Martin, C.J. (2014) The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism? *Ecological Economics,* 121, 149-159

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2018). Designing microgrid energy markets: A case study: The Brooklyn Microgrid. Applied Energy, 210, 870-880.

North D, 1990; Institutions, Institutional Change and Econonmic Performance. Cambridge University Press.

Ostrom, E. (1996) Crossing the Great Divide: Coproduction, synergy, and development. *World Development,* 24, 1073-1087.

Ostrom, E. (1999). Coping with tragedies of the commons. *Annual review of political science,* 2(1), 493-535.

Ostrom, E. (2009) A general framework for analyzing sustainability of Social-Ecological Systems. *Science,* 325, 419-422.

Parra, D., Swierczynski, M., Stroe, D. I., Norman, S. A., Abdon, A., Worlitschek, J., ... & Bauer, C. (2017). An interdisciplinary review of energy storage for communities: Challenges and perspectives. *Renewable and Sustainable Energy Reviews*, 79, 730-749.

Siano, P. (2014) Demand response and smart grids-A survey. *Renewable Sustainable Energy Reviews*, 30, 461-478

Smil, V. (2010). Energy transitions: history, requirements, prospects. ABC-CLIO.

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy,* 28(12), 817-830.

von Wirth, T., Gislason, L., Seidl, R. (2018). Distributed energy systems on a neighborhood scale: Reviewing drivers of and barriers to social acceptance. *Reneweble Sustainable Energy Reviews* 82, 2618-2628.

Wolsink, M. (2012). The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. *Renewable Sustainable Energy Reviews,* 16, 822–835.

Wolsink, M. (2018) Co-production in distributed generation: renewable energy and creating space for fitting infrastructure within landscapes. *Landscape Research* 43 (4) 542-561.

Wüstenhagen, R, Wolsink, M, Bürer, M.J. (2007) Social acceptance of renewable energy innovation. *Energy Policy* 35, 2683-2889.