Viability of Self-Governance in Community Energy Systems
Structuring an Approach for Assessment

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Abstract

This paper sets out to formulate a structured approach to assist in analyzing the viability of self-governance in community energy systems. Existing research in self-governance in the framework of socio-ecological systems provides a basis for analysis in applications concerning socio-technical systems, but more than a basis is needed. Although the socio-ecological system framework can easily be `translated` to the socio-technical system, operationalizing the ecological variables in the technical context is troublesome. Therefore, a new theoretical approach is proposed employing two dimensions of variables: social and technical complexity. In laying out multiple different configurations of energy systems along these dimensions, a hypothesis is given, proposing an increasing need for polycentric governance corresponding to increasing social and technical exigency. Exploring possible system configurations along these dimensions leads to an important nuance. The viability of self-governance in community energy systems may lie in the communities' abilities to be adaptive to coordinate with different governance circles; self-governance can take many different forms. A method of classification of different types of self-governance, based on the degrees of social and technical complexity, is therefore conceived. Local biogas networks are considered to be one possibility where self-governance might be a feasible and desirable governance structure. We therefore refer periodically to a biogas arrangement to illustrate the proposed approach.

Keywords: community energy system, polycentricity, self-governance, social and technical exigency, socio-ecological systems, socio-technical systems

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1. Introduction

In wake of the liberalization of energy markets and a transition to the use of more renewable energy sources, the concept of self-governance is gaining prominence. Not only is distributed generation emerging as a credible alternative to central electricity production, it is also possible for villagers, neighbours, farmers, and small businesses, to organize the delivery themselves and switch from dependence on network companies to proactive and coordinated self-provision.

This transformation from individual consumer to networked prosumer[2], however, does not necessarily mean that self-governance is a feasible and desirable way of operating future community energy systems. It remains to be seen, for example, in how far the concept of self-governance is applicable to complex adaptive socio-technical systems, which can involve a great variety of public and private actors within a specific institutional environment that enables and constrains them, and that have a strong emphasis on technical complementarities requiring considerable expertise and daily, if not hourly, supervision to manage.[3]

This theoretical paper sets out to explore what opportunities and limits there may be for self-governance in community energy systems. Much research has been conducted looking at the compatibility of self-governance in socio-ecological systems. There are useful parallels to note between these two different types of systems, and the analyses conducted in the socio-ecological system can be instructive for our purposes. However, difficulties arise when operationalizing analysis of self-governance viability in these socio-technical systems. In order to better analyze and understand this viability, a theoretical framing is developed to analyze these community systems. Two variable-axes are proposed where technical complexity and social complexity are increasing along the 'x' and 'y' axes, respectively. This structured approach stylizes different community energy system configurations, relating them to dimensions of social and technical complexity. Nine such social and technical configurations are categorized. Increasing complexity along these two axes is hypothesized to correspond with decreasing ability for self-governance to be sufficient as a stand-alone mode of governance. This assessment of self-governance viability reveals an important nuance; variety and context-specific adaptability of self-governance arrangements is also demonstrated in the framing. Based on the rough taxonomy of system configurations, a corresponding matrix of possible governance arrangements is outlined. It is suggested that with increased social and technical exigency, increased potency of polycentric arrangements should be anticipated to provide a robust governance arrangement.

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[2] A prosumer is a consumer of energy, who also produces energy (think wind turbine, anaerobic digester, etc) either for their own consumption or for others (insert reference source?).

[3] Assuming here for a moment that smart energy technologies cannot fully automate it.

The next section defines self-governance and introduces the work that Elinor Ostrom has done in analyzing the viability of self-governance in socio-ecological systems. The section continues with a description of the possibilities and difficulties of bringing this analysis to the socio-technical system context. Section 3 proposes a new methodology for analyzing the viability for self-governance in community energy systems, as one type of socio-ecological system. The revealing of the multiplicity of self-governance forms is then elaborated. In Section 4 we reflect upon what theoretical challenges are present and what insights have been gained in the development of the methodology. Section 5 provides conclusions with recommendations for further research.

2. The Case for Developing another Self-Governance Assessment Approach

2.1. Self-Governance

The concept of governance is subject of discussion across a broad array of fields within the social sciences. For political scientists, for example, governance is closely related to government and state institutions, national policy goals, the concept of order in society, and a process of interactions between political bodies and other societal entities. Fukuyama, for example, defines governance as "a government's ability to make and enforce rules, and to deliver services, regardless of whether that government is democratic or not" (Fukuyama 2013, 4).[4] Writing about what governance is and does, Meadowcroft (2007) refers to "the varied ways order is generated in modern society...encompass[ing] public debate, political decision-making, policy formation and implementation, and complex interactions among public authorities, private business and civil society..." Economists[5], in contrast, like to frame governance rather as creating order in markets rather than society, an order that promotes efficient market functioning / outcomes, welfare considerations, and then classify governance in terms of the degree of government intervention in markets. We can complement this with an excerpt from one of Oliver Williamson's more recent papers (2005), which reads: *"The economics of governance is an effort to implement the "study of good order and workable arrangements,"1 where good order includes both spontaneous order in the market, which is a venerated tradition in economics (Smith, 1776; Hayek, 1945; Arrow and Debreu, 1954), and intentional order, of a "conscious, deliberate, purposeful" kind (Barnard, 1938, p. 9). Also, I interpret workable arrangements to mean feasible modes of organization…".*

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[4] "In this conceptualization, the quality of governance is different from the ends that governance is meant to fulfil. That is, governance is about the performance of agents in carrying out the wishes of principals, and not about the goals that principals set." P4 Fukuyama.

[5] From Oliver Williamson (19.. , 19..) to the World Bank (Kaufmann, et al 1996?) and from Elinor Ostrom (2005) to Rhodes (1996), a rich body of literature embodies the studious labor that has gone into demonstrating the essential role that governance constitutes in human organization, and the impact proper governance can have in the development of countries. Moreover, what governance can mean for political / social alignments, and even what governance can mean for ecological systems.

Consolidating, we provide our working definition of governance in general:

Governance: *the intentional but ubiquitous shaping and guiding of collective human behaviour by various means (negotiation, law, policy, norms, monitoring, penalty, reward, etc.) within various arrangements (government-oriented, market-oriented, community-oriented).* [6]

The concept of self-governance is still a relatively undeveloped terminology. It may refer to an individual or group of people that exercise control over oneself or themselves. It can be used to describe a community that is able to "exercise all of the necessary functions of power without intervention from any authority which they cannot themselves alter" ("Self-governance," *Wikipedia, the free encyclopedia*).

Self-governance is commonly associated with forms of self-government, autonomy, or self-rule, as opposed to colonial or external rule and closely related to ideas on representative democracy. For example, to C. Bird, talking about self-governance in relation to republican government in the US, describes self-governance in the following way:

"a political community or organization is self-governing [when] in some sense or senses the actions or controls imposed by its governing institutions can be thought of as originating from within that community or organization" (Bird 2000, 563-564).

Vincent Ostrom made similar comments when talking about the fact that government is not an entity independent of its people ready to intervene in an otherwise-free flowing market. Rather the multiple layers and bodies of government are constituted of, "a nexus of relationships within which people participate in their governance, not as a choosing entity that intervenes into a society to alter equilibrium outcomes" (R.E. Wagner, 180). For Ostrom, it was therefore paramount that there be two prevailing, flourishing attributes to a functioning democracy: it should be polycentric (a rich nexus of coordination with multiple centers of power) and it should be self-governing. Indeed, in this sense, a federal state is not just the decentralization of the State power via delegation of the State. Rather, it is, in its ideal condition, the multiple layers of power amalgamated into a fully functioning body.[7]

With her extensive work in socio-ecological systems, Elinor Ostrom identified and elaborated upon where self-governance proved to be a robust mode of governance, and where governments and markets would

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[6] For further reading on governance: Fukuyuma 2013, Meadowcroft 2007, Williamson 2005.

[7] It is reasonable to say that Vincent admittedly did not see democratic federal states to be consistent mechanisms of polycentric and self-governing arrangements, but that they *ought* to be. Likewise, implied in Elinor's soft, yet unbending, words, there is the consistent *aim* to find the opportunities of self-governance. E. Ostrom looked upon polycentricity as both a herald of hope as well and a beacon for success of self-governing community arrangements for the care of common resource goods.

perform less adequately, or even fail. All the more is this mode of governance effective if it is found among a multiplicity of governing layers enveloping the action situation (Ostrom 2005, see chapter nine).

Her work therefore brought self-governance down from Vincent Ostrom's self-governance of (large) political bodies to local community self-governance. Elinor Ostrom's central proposition is that common pool resources, empirically, are not pre-destined to head toward the tragedy of the commons scenario (G. Hardin 1968, M. Olson 1965). Nor are modes of governance constrained historically in these common pool settings to merely the Market or the State, as so many theorists would have it. Rather, what Ostrom discovered is that many of these common pool resources were governed in a way that endured time and that were governed by the users themselves in a coordinated way (Ostrom 2005). Conversely, nationalizing previously self-governed forests in Thailand, India, and Africa, for instance, has had negative outcomes (ibid, p. 221). She also proposes that the robustness of the self-governance scenario will be dependent on certain specified attributes of a resource and of the community using those resources; self-governance can be a robust mode of organization, especially if certain attributes of the resources and users are in place.

2.2 Self-Governance in Socio-Ecological Systems

To assist in our understanding of the prospective role that self-governance may play in socio-technical systems, it is helpful to consider self-governance in the context of socio-ecological systems. The reasons for this are two-fold. First, socio-ecological systems have been extensively studied with respect to self-governance. Secondly, specific effort was taken by scholars to determine viability of self-governance within socio-ecological systems.

Self-governance has been shown to fit extremely well with communities governing their own natural resources (Maine lobster fishery, Acheson 1988, 2003; Pacific salmon fisheries, Singleton 1998; New Mexico indigenous irrigation communities, Cox 2008, etc, - the empirics seem exhaustless) to the extent that John Commons' proposition of threat to common pool resources due to over-extraction of greedy individual users is completely midigated, notwithstanding severe external shocks (Cox 2008).

By way of extracting from the spaghetti of empirics two clear sets of attributes that help identify in what situations self-governance may be adeptly chosen by the appropriators of a resource, Elinor Ostrom made an important contribution that goes beyond merely demonstrating that self-governance can be a robust option for communities. Ostrom identified the attributes of these appropriators, and of the resource they are interested in as highly relevant to the success of their governance.

The following table is comprised of these attributes:

Table 1. Resource and Appropriator Attributes

Resource Attributes	**Appropriator Attributes**
R1 Feasible improvement	A1 Salience
R2 Indicators	A2 Common Understanding
R3 Predictability	A3 Low Discount Rate
R4 Spatial Extent	A4 Trust & Reciprocity
	A5 Autonomy
	A6 Prior Organizational & Local Leadership

Source for Table and Definitions: (Ostrom, 2005, pp. 244-245)

Attributes of the Resource

R1 Feasible improvement: Resource conditions are not at a point of deterioration such that it is useless to organize, or so under-utilized that little advantage results from organizing.

R2 Indicators: Reliable and valid indicators of the condition of the resource system are frequently available at a relatively low cost.

R3 Predictability: The flow of resource units is relatively predictable.

R4 Spatial Extent: The resource system is sufficiently small, given the transportation and communication technology in use, that appropriators can develop accurate knowledge of external boundaries and internal micro-environments.

Attributes of the Appropriators

A1 Salience: Appropriators depend on the resource system for a major portion of their livelihood or the achievement of important social or religious values.

A2 Common Understanding: Appropriators have a shared image of how the resource system operates (attributes R1, 2, 3, & 4 above) & how their actions affect each other & the resource system.

A3 Low discount rate: Appropriators use a sufficiently low discount rate in relation to future benefits to be achieved from the resource.

A4 Trust & Reciprocity: Appropriators trust one another to keep promises and relate to one another with reciprocity.

A5 Autonomy: Appropriators are able to determine access and harvesting rules without external authorities countermanding them.
A6 Prior Organizational & Local Leadership: Appropriators have learned at least minimal skills of organization and leadership through participation in other local associations or learning about ways that neighboring groups have organized.

We will elaborate further on some of these attributes when looking toward applications to community energy systems.

2.3. Community Energy Systems

Increasing fossil fuel scarcity and deteriorating environmental conditions call for a transition towards a more sustainable energy system (Dorian et al. 2006; Rifkin 2002). This transition is gaining speed within the EU in general (Verbong & Loorbach 2012). Eurostat even shows a doubling of renewable energy production in the last decade (Eurostat 2012), and within the Netherlands in particular, with the 'regeerakkoord 2012' setting ambitious targets towards a fully sustainable energy supply by 2050. Many of the renewable energy technologies envisioned in this respect have a local, distributed character in terms of generation and transport, and would often be facilitated by smart grid technologies. Solar PV panels on household roofs, wind turbines, and biogas networks are examples of this.

The combination of a more liberalized and privatized energy market and the development of more decentralized renewable energy technologies, allows for more localized forms of energy system operations and governance. "In Germany, for example, half of the newly installed renewable energy capacity is owned by citizens, farmers and energy cooperatives (Trend research 2011)" (Middlemiss & Parrish 2010; Hisschemöller & Sioziou 2013). In other words, consumers have also become producers, i.e. 'prosumers', and are no longer merely individuals, but increasingly self-organized collectives. Currently, over 300 of such collectives exist in the Netherlands alone (HIERopgewekt 2013).

Community (renewable) energy systems are considered to differ from other bottom-up renewable energy initiatives; but how exactly? Is it their charitable or non-profit status, their involvement of public buildings, or the involvement of local people in project development? According to Walker and Devine-Wright (2008, p. 498) two core dimensions of community energy systems underlie views of policy makers, administrators, activists, project participants, and local residents. "First, a *process* dimension, concerned with who a project is developed and run *by*; who is involved and has influence. Second, an *outcome* dimension concerned with how the outcomes of a project are spatially and socially distributed – in other words, who the project is *for*; who it is that benefits particularly in economic and social terms."(ibid p.498). In other words, a distinction is made between open, participatory and closed, institutional processes on the one hand and local, collective and distant, private outcomes on the other. In this light, community energy systems are about “a high degree of involvement of local people in the planning, setting up and, potentially, the running of the project” and the local collective distribution of benefits (ibid, p. 498). This would lead to a cohesiveness of governance that is fused with the community itself.[8]

Next to this more socio-economic conceptualization of community energy systems stands their techno-operational dimension. Like the national electricity and natural gas infrastructures, community energy systems do not revolve around a mere commodity, but represent complex and adaptive network industries that demand great expertise to operate. They necessitate clearly defined operational roles and responsibilities of the various actors managing the physical flow of energy from producers to consumers via networks and require the various tangible assets or artifacts that make up the supply chain, such as pipelines, wires, pressure stations, generation plants, etc. to work together in a complementary fashion and in a certain order. Special attention in this respect goes to the control systems or mechanisms[9] and infrastructure design principles[10] that are used to coordinate the flow of energy, information, or funds through complex transportation and distribution systems (Nightingale et al. 2003, pp. 477-478).[11] Assets need to be managed, (collective) investment decisions made, systems operated and balances maintained, and disturbances handled if these system are to be reliable (Scholten 2013, p. 178).[12] In this light, Finger et al. (2006) distinguish four technical functions that can be considered critical for safeguarding the technical complementarity of infrastructures: interoperability, interconnection, capacity allocation, and

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[8] This perspective is close to that of grassroots innovation (GI), as developed by Seyfang et al. (2010, pp. 6-7). GI describes “innovative networks of activists and organizations that lead bottom-up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved” (Seyfang et al. 2010, p. 6).

[9] Well-known examples are the supervisory control and data acquisition systems (SCADA) and energy management systems (EMS) (Rinaldi et al. 2001, p. 14).

[10] Prominent examples of such infrastructure design principles are the N-1 redundancy criterion, wherein a system of N components should be able to continue operations if a single component would randomly fail (Barabasi 2003), or building more resilient network structures that enable rerouting flows.

[11] Because of these control mechanisms and design principles most failures are dealt with in time, i.e. before they escalate. Massive failures only tend to occur when a system experiences multiple failures in design, equipment, operation, procedures, or environment at the same time (Perrow 1999a; 1999b).

[12] First, the assets or equipment of energy infrastructures simply need to function properly. Second, there should be sufficient investment to ensure that adequate future production and transport capacity is available to meet long-term demand. Third is the daily operation of the system as a whole, i.e. the ability to meet demand under normal operating conditions. This relates foremost to the balancing of energy loads and flows across the network in real time, checking pressures and quality, congestion management, and dealing with intermittent production on the supply side and demand fluctuations (seasonal changes, daily quantity, nature, or location) on the other end. Finally, reliability refers to disturbance response, i.e. the ability of an infrastructure to continue operations in the event of equipment outages, or safeguarding system integrity, i.e. “the capacity of the overall system to correct errors or unexpected outages of network elements in a way that operations can be maintained, at least in parts of the infrastructure” (Finger et al. 2006, p. 4).

[12] Interoperability focuses on the “mutual interactions between network elements” and as such “defines technical and institutional conditions under which infrastructure networks can be utilized” (Finger et al. 2006, pp. 11-12). Interconnection deals with the “physical linkages of different networks that perform similar or complementary tasks” (Finger et al. 2006, pp. 11-12) and is closely related to technical system boundaries. Capacity allocation concerns the allocation of “scarce network capacity to certain users or appliances” (Finger et al. 2006, pp. 11-12), i.e. the “allocation of existing resources in order to meet the expected demand” (Künneke and Finger 2007, p. 309). Issues pertain to questions about the scope and capacity of the network, access rights, and the facilitation of actual access. Finally, system control “pertains to the question of how the overall system (e.g. the flow between the various nodes and links) is being managed and how the quality of service is safeguarded” (Finger et al. 2006, pp. 11-12).

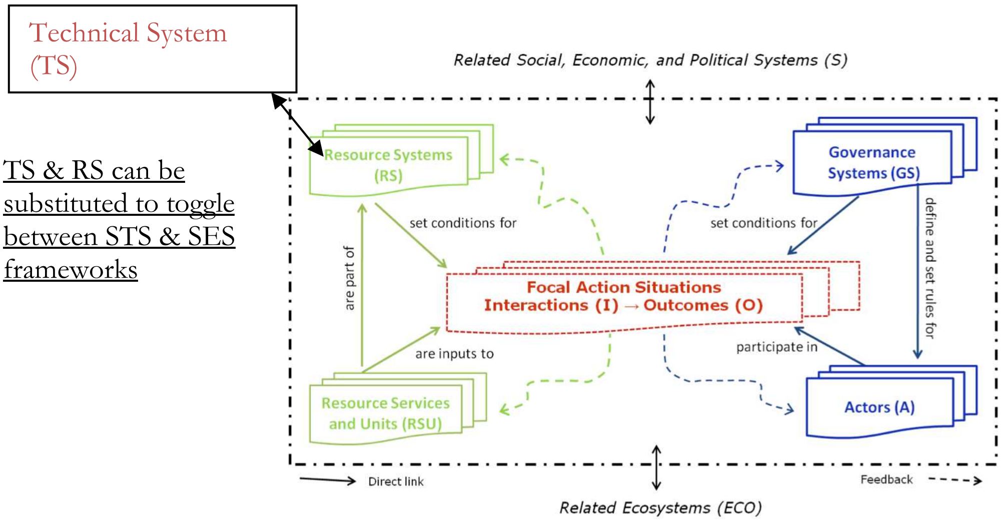
system control.[13] The notion of socio-technical systems hence fits well to describe community energy systems.

Summarizing, a community energy system is a technical system which subsists upon a high degree of participation from the community which it serves. This participation may be in the form of initiative and implementation, or operations and expansion, or all the above. The system is not forcibly independent of other systems, nor is it necessarily operated entirely by the community. Therefore, degrees of 3rd party involvement at any point in the supply chain of the system are likely. Indeed the ramifications of system change upon existing third party actors, such as DSOs, or service providers, and the ensuing cyclical effect then upon the community, are not to left to be left untreated in through this analysis.

2.4. Assessing Self-Governance in Socio-Technical Systems - Highlighting the Difficulties

At a framework[14] level, it has been demonstrated that a high level of compatibility is found in treating socio-technical systems, using a modified form of a socio-ecological system framework. Rolf Künneke (2011) employs Elinor Ostroms SES framework, and derives from it a very similar framework for STS, with one simple modification. To make the transition from SES to STS, we need only substitute one pillar of the framework (Resource Systems) with another (Technical System):

Figure 1: Transition from Socio-Ecological System Framework to Socio-Technical System Framework



<u>TS & RS can be substituted to toggle between STS & SES frameworks</u>

Sources: Ostrom 2000, Künneke 2012

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[13] Central to this view is that infrastructures are "erected and structured around a certain technical core of physical artifacts [that are] embedded in, sustained by, and interact[ing] with comprehensive socio-historical contexts" (Ewertsson and Ingelstam 2004, p. 293; Hughes 1983, p. 465)." The obvious peculiarity of this perspective is that it does not follow an exclusively technical topology of infrastructures (like Barabasi 2003, Newman 2003) but considers the interaction of the integrated physical and social / organizational networks a crucial element in determining system performance (Kroes et al. 2006; Kaijser 2005; Nelson 1994; Geels 2004; Weijnen and Bouwmans 2006).

[14] For clear definitions of , and delineation between, framework, theory and models: Ostrom 2005 pp.27-29

While the framework transition is apparently smooth, the operationalization of analysis remains difficult, when drawing from the 'tools inside the boxes' of this framework. Given the strong relevance of resource and user attributes to SES analysis, it would be the logical next step to bring these attribute categories to the STS context whilst checking the viability of their use in the CES case. If we do so, the user attributes seem to align reasonably well with the CES context, while the attributes of resources which are sub-components of the left-hand side categories in the above diagram, have inconsistent, and largely negligible relevance when applied to technical systems, making analysis with any predictive results elusive. These weaker linkages are briefly analyzed here:

Given that we are focusing this work of social-technical system application to community energy systems, and given that today's community energy systems, in principle, are either new or not yet existing, *feasible improvement* would not be a factor that carries determinant weight in an analysis of CES. It can reasonably be taken as granted that any modern community energy system under consideration will not suffer from deterioration of the mechanical system, nor of any resource that feeds it, in such a way that the participants would be disincentivized to self-organize. It is however possible that the system is so 'underutilized'[15] that little advantage would be realized in self-organizing. This would be the case in the sense that the costs of system implementation would be insurmountable in light of inadequate benefits of implementation. In this instance, subsidies and external third-party funding can be instrumental in the realization of a project. This second aspect is relevant to the question of viability of a project, but not as it necessarily relates to the compatibility of self-governance with a given system.

The presence of reliable and valid *indicators* of the condition of the resource system is pertinent, in that indicators of system performance are certainly necessary. But with a technical network, there is no question that there will be monitoring and sensory subsystems installed. This is an example of the analytical gap that exists between SES and STS when approaching the higher resolution of analysis. In the commons, you may have resources where indicators of the condition are not obvious. Nor are they in existence, just because the system is in existence (think salmon fishing). But with a technical system, indicators are part-and-parcel of the existence of the system itself, by design. The presence of indicators therefore cannot be justified as a determinant variable in the analysis of a CES.

Predictability may be instrumental in terms of the viability of the initiation and continuation of an energy system, particularly on a local level. But as far as being a direct determinant of the viability of self-governance of that system, it is not a feasible role. Certainly all energy systems need a certain degree of predictability with respect to feedstock, but if there is a lack of predictability, it will not just be the local community who will shun the governance of the system; DSOs or any other third party would as well.

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[15] *Underutilized*, is the word used by Ostrom in the SES context; in the case of community energy systems, *underdeveloped* may be more fitting.

One relevant element that we can carry forward with us into analysis of CES, however, is that it may be that degrees of unpredictability may require a local system to depend more on higher level systems that can provide back-up, whenever necessary. But again this is not a central issue with respect to the viability of self-governance itself.

Whereas *Spatial Extent* in the *SES* context is to be constrained if knowledge of local appropriators is to be adequate to understand the microenvironments within the system (as well as the peripheral boundaries), the constraint of *Spatial Extent* is relevant in *STS* in a different dimension. That dimension we can label technical complexity. It is quite possible (though not a given) that increased size of the energy system can lead to increased complexity in managing the technical system. But, strictly speaking, we would do better to speak of *System Size,* to be more inclusive of elements beyond geographic space alone. This will be discussed further in the next section.

In summation, the transposition of resource attributes (identified as determinant variables for self-governance in socio-ecological systems), upon socio-technical systems (as a variable with descriptive capacity of self-governance in community energy systems) simply does not work very well. The resource attributes do not demonstrate strong logical alignment with the relevant aspects of a technical system, that of a community energy system. When going into deeper analysis, beyond the establishment of a framework to the utilization of it (SES/STS), more analytical tools need to be developed to operationalize the analysis in the STS context.

3. A New Approach to Assess Viability of Self-Governance in Socio-Technical Systems

3.1. Social & Technical Complexity

We do not want to be too narrow in our considerations of what comprises our usage of these two types of complexity, as it is precisely on the broad stage of inclusiveness that complexity takes its bow. Employing the concept of complexity, the scope of analysis maintains simultaneously breadth and specificity, to have bearing upon the individual constituent parts of the system, but in a "non-reductionist manner" (S.M. Manson 2001). By approaching the dimensions of complexity, we can remain quite inclusive of the components, while retaining analytical acuteness, focusing on the elements that create increased or decreased challenges with respect to the interactions between human actors, interactions between technical components, and, ultimately, interactions between the technical and the human. However, it should be noted that 'complexity' is used here in a general sense. We therefore use technical and social 'exigency' interchangeably with 'complexity'.

We begin with the human interactions and boil down social complexity to these four ingredients:

1. Number of actors
2. Heterogeneity of actors
3. Interpersonal dynamic
4. Structure of transactions[16]

The *number of actors* within a community energy system is a clear variable to focus attention on. But this, we believe would be too narrow if treated independently from the other variables. Indeed, much research has gone before, looking for patterns of governance, using numbers of community participants, or group size, as a determinant variable (from Ostrom 2005: Barker et al. 1984; Cernea 1989; Wilson and Thompson 1993; Meinzen-Dick, Raju and Gulati 2002, Libecap 1995, Tang 1992, Agrawal 2000, Marwell and Oliver 1993, Chamberlin 1974; R. Hardin 1982). But as Chamberlin and Hardin concluded, there are too many other variables that change at the same time group size increases or decreases, making group size alone an inadequate factor in rigorous analysis.

A second factor therefore could be looked at: *heterogeneity of the actors* or actor groups. By heterogeneity, we mean what degree of disparity between the likeness of individuals or groups. It is logical that the number of participants may not be as influential on system performance, as the conflicts or harmony that exists between those participants. But the reliability of this variable alone, too, is contestable (from Ostrom 2005: Baland and Platteau 1996; Platteau 2004). It is both difficult at times to detect, as well as difficult to determine its effect. Therefore, it plays a part in the social dimension, but cannot be depended upon entirely as a unique dependant variable.

With respect to social complexity, we do not want to limit our observations to the actors themselves, nor alone to the interaction of user and machine, but to include as well the interactions and social make-up of the various actors involved. This interaction would include both the type of interaction (the difficulty, or smoothness of interaction) as well as the frequency and composition of interaction. The former component we label *interpersonal dynamic*, and the latter, *structure of transactions*.

It would take no insignificant amount of text to lay out thoroughly what is contained in 'technical complexity'. We will limit ourselves[17] to lay out our usage of the terminology in a simplistic manner that highlights four main components:

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[16] To include frequency of transactions and political and market structures within which transactions and coordination take place

[17] For further reading on complexity as it relates to energy infrastructure: Next Generation Infrastructures, TU Delft is a helpful resource: http://www.nextgenerationinfrastructures.eu/download.php?field=document&itemID=430790. You may also find the following compilation of present work in the European Commission on complexity science in smart grids helpful for up-to-date sources and ongoing work: http://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/documents/ld-na-25626-en-n.pdf

1. Number of technical components
2. Heterogeneity of technical functions
3. Control mechanisms
4. Infrastructure design criteria / network topology

Quantity of technical components is one basic gauge of how complex a system may be. Its advantage is that quantities are more visible and easily identifiable. A disadvantage is that it can be misleading if considered independently from other indicators.

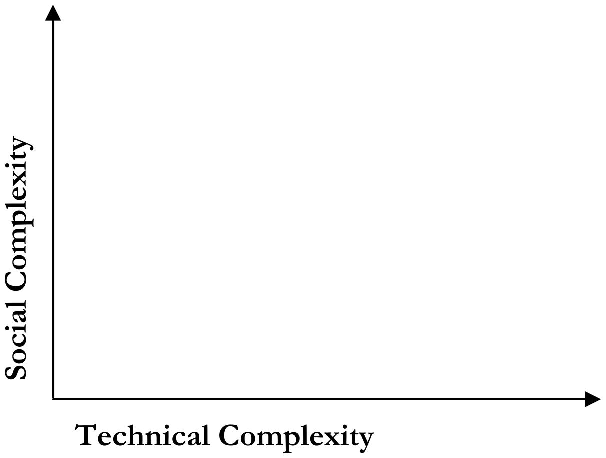
One such other indicator is the *heterogeneity of the technical components and their functions*. In essence, the more diversity in components the more complex the system, particularly with respect to their interactions and the impacts of those interactions on the error propensity of a system. High degrees of difference between sub-systems, for instance, within the system can lead to increased difficulty of handling process and outcomes of operations. Another example would be whether all critical technical functions as mentioned above would have to be addressed.

Of course, the mechanics themselves alone, while numerous and heterogeneous, may be quite complex, while the operations, the handling of the machinery, and execution of its utility may, or may not be complex. In other words, how many operators are required for facilitating the relevant *control mechanisms* or control systems, under what time constraints do they need to act, with which scope of control are they dealing, with how much repetitiveness, and for what duration? The knobs, valves, buttons, levers, software and interfaces – are they constructed in such a way as ease the management of operating a complex system?

It is feasible to consider that at times functions may be contradictory, overly redundant, or concealing of other functionalities, or imbedded and undetected. Convoluted arrangements and resulting confusion is may likewise be partly a matter of *infrastructure design*. Certain network topologies, automated control, and redundancy measures on the other hand can prove instrumental in preventing operational issues from arising in the first place.

These two variables, technical and social complexity, can be laid out graphically in the following way:

Figure 2. Plotting Community Energy Systems via Complexity



A community energy system, based on the composition of its technical and social components could be plotted along these two axes. Upon this framing could be placed any assortment of different community energy systems in a region or country, for instance. Where there is increasing complexity due to the variations in the four components listed above for each camp of complexity, the energy system would be higher than its less complex counterpart.

In Figure 3 is a layout of nine basic stylized cases of energy system configurations, outlining fundamental possibilities accounting for a theoretical survey of typical, local, bio-gas related systems. The nine stylized types are therefore not fixed into a designated matrix, strictly speaking, but are merely possible arrangements that represent the dimensionalization along these two axes. There may also be varying 'space' between these possible configurations represented by the boxes, in the sense that several different possible configurations would also lie between the boxes along the spectrum of complexity, if the resolution of the analysis was to be increased. The aim here is simply to harness a couple sound dimensions that lend a variable to analyze CES in a way that one system can be compared to another in terms of its compatibility with self-governance.

On the outlay of possible local biogas configurations below, a specific case has been chosen to highlight as a way of illustrating some of the application of this methodological framework. The Texel Island biogas case[18] has been plotted to fall on the stylized case where technical complexity is considered relatively high,

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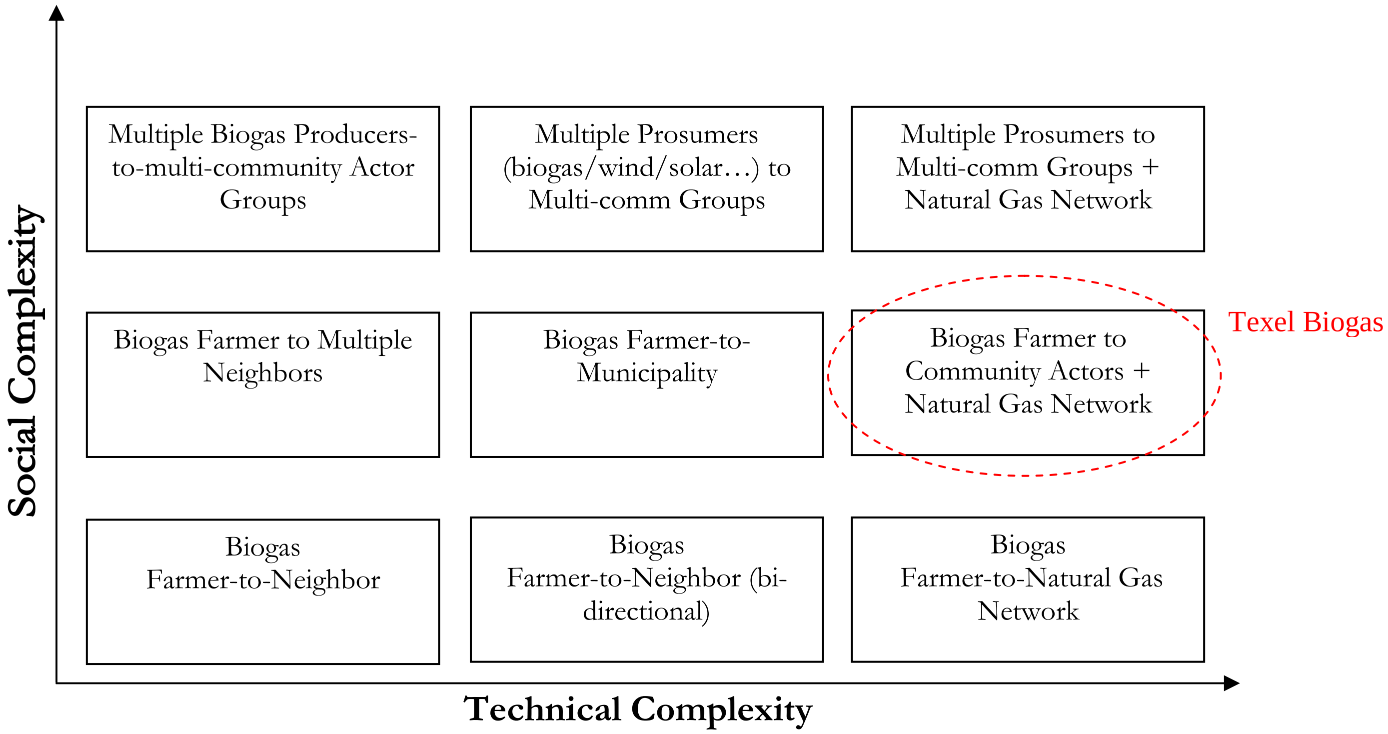
[18] Texel Island is the largest of the five Friesian Islands off the coast of the Netherlands in the Wadden Sea, the shallow coastal island waters of the North Sea. At a population of 13,779 it is also the most populated island. Seven villages are on the island, but the municipal authority rests at the island level. Even with several villages and thousands of residents, the islands maintains a strong sense of community. In 2007 the island of Texel, Netherlands adopted the Wadden Manifesto, agreeing to achieve energy (and water) independence by 2020. In this context, the local energy cooperative, Texel Energie, and a local farming family have been working toward developing a biogas plant. The actors involved include: the community energy cooperative, Texel Energy, the many customers on the island (many of whom are also shareholders in Texel Energy), the province who is providing funds for such projects specifically for the Wadden islands, the farming family providing the source for the biogas, and the DSO operating the gas network that feeds the grid from the mainland, and the grid on the island itself.

and social complexity mid-range. This case involves multiple social arenas, but with a strong central coordinating local body. The technical system is relatively demanding, upgrading the biogas to natural gas specifications, and injecting into the existing DSO-operated grid, with the hope of eventually supplying the island's needs for gas, all by local production.

Figure 3. Texel Biogas in a General Layout of Possible Biogas Network Configurations

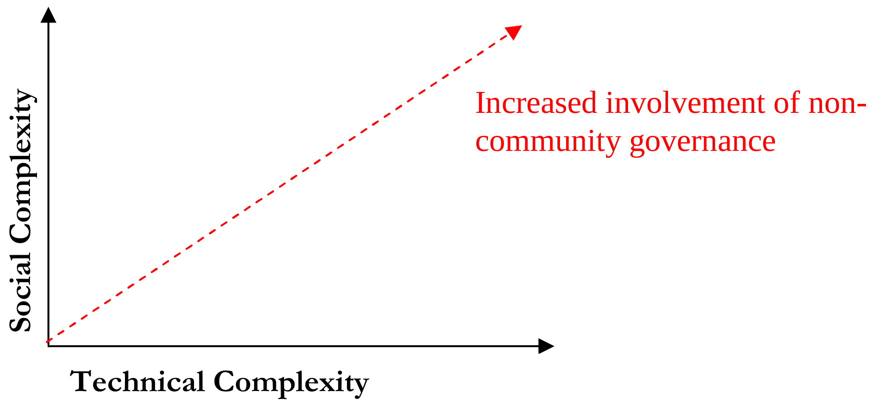


Biogas production, cleaning, pressurization, odorization, injection, balancing, monitoring, and retailing is an involved process. There would be a possibility for even higher technical complexity, if increased interaction with the electricity grid were to be implemented via a power-to-gas installation, or gas-to-power. Although these would theoretically be possible for the island, they are not being considered as immediate options. This illustrates that complexity is always relatively less than another option, and greater than yet another. Further, this relativity may have bearing on the modes and specificities of governance.

3.2. Hypothesis

As complexity increases in social and/or technical aspects, pressure increases on local participants if they are the ones designing, implementing, or maintaining the governance of the system. Greater demands for expertise of subsystems and systems increases, requiring more resources allocated to the governance of the system. Wading through the multiple layers of government, multiple circles of interest groups, and multiple neighbors, friends, and relatives can also become an exceedingly difficult swim. Therefore involvement of high-resource expertise, and third-party objectivity, becomes essential. At the community level, you witness a trend for increased need for 'intervention' from more centralized organization, which is supported by the logic that greater technical complexity requires more skill-knowledge than a community may possess. Further, increased social complexity can find greater certainty and political simplification in third-party involvement - the DSOs, for instance[19].

Figure 4. Increased Complexity & Decreased Viability



Those familiar with transaction economics will recall Oliver Williamson's powerful demonstration of the increasing transaction costs via increasing coordination needs requiring more efficient coordination through vertical, non-contracted, modes of organization (Williamson 1997).

However, it is not here hypothesized that even at higher levels of complexity, the community participants' functions are of necessity completely sidelined (though it could be). Advantage is not necessarily always brought when heirarchy and centralized management is introduced to *replace* existing community structures. The local intimate knowledge of network surroundings, feedstock, local resource topology, etc. can be difficult to replicate and-or replace via centralized bodies. C. Perrow (1984, 1993, 1999) proposes that when a system's interactive complexity is increasing, there is a parallel increase in the requirement for decentralized management.

Observing systems small enough and close enough to the community itself, we propose that reconciliation between the Williamsonian and Perrowian hypotheses, so to speak, is found in the *addition* of centralized governance on system scale to the local community participation (without eliminating it). This may safeguard the durability of the system without extensive transaction cost inefficiencies, given that the community energy systems already have a pre-existing 'incumbent' community already in place.

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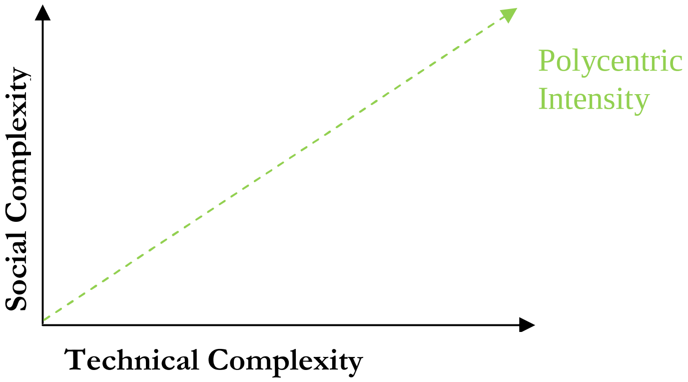
[19] At the EDGaR A11 taskforce group meeting, Delft, April 2012 disucssion among the DSOs referred to examples of communities 'outsourcing' entirely to the DSO the energy systems that they had once endeavored to create.

These multiple arenas of simultaneous and semi-autonomous governance circles are a governance design/outcome that Vincent Ostrom treats extensively and employed in his work within political science (V. Ostrom 1973, V. Ostrom 1997, R.E. Wagner 2005). He termed this arrangement, polycentricity. It is our proposition that this polycentric tendency increases with increased social and technical complexity. With highly centralized arrangements, such as a state owned utility in an autocratic government, you can expect a very limited 'diversity of governing bodies with independent autonomy, interacting in a coordinated manner' (voila, a definition of polycentricity). Conversely, highly decentralized arrangements may also not require such a dynamic arrangement of interacting governance layers and spheres. A biogas farm in an extremely remote area with full autonomy and technical independence certainly does not require a high intensity of polycentric governance. But as we see, de-central community energy systems may coordinate with network operators or even amalgamate to coordinate with each other, and in such instances, demand intricate reformulation of coordinated governance, not just a blanket-governance solution to meet all needs at all levels and in all situations.

Figure 5. Complexity & Polycentricity



Referring back to the Texel Island example, a fair prediction based on this hypothesis would be that there would be a continued engagement from the part of the community, but there would be the simultaneous coordination with, and contracting to, DSOs or relevant ESCOs. There would be an expectation for both community participation perhaps in the form of cooperatives, as well as the dependence on third party specialized services[20]. Figure 6 demonstrates the previous layout, but with various governance options transposed upon the plotted stylized options.

Figure 6. Texel Biogas and a General Taxonomy of Self-Governance of Biogas Networks

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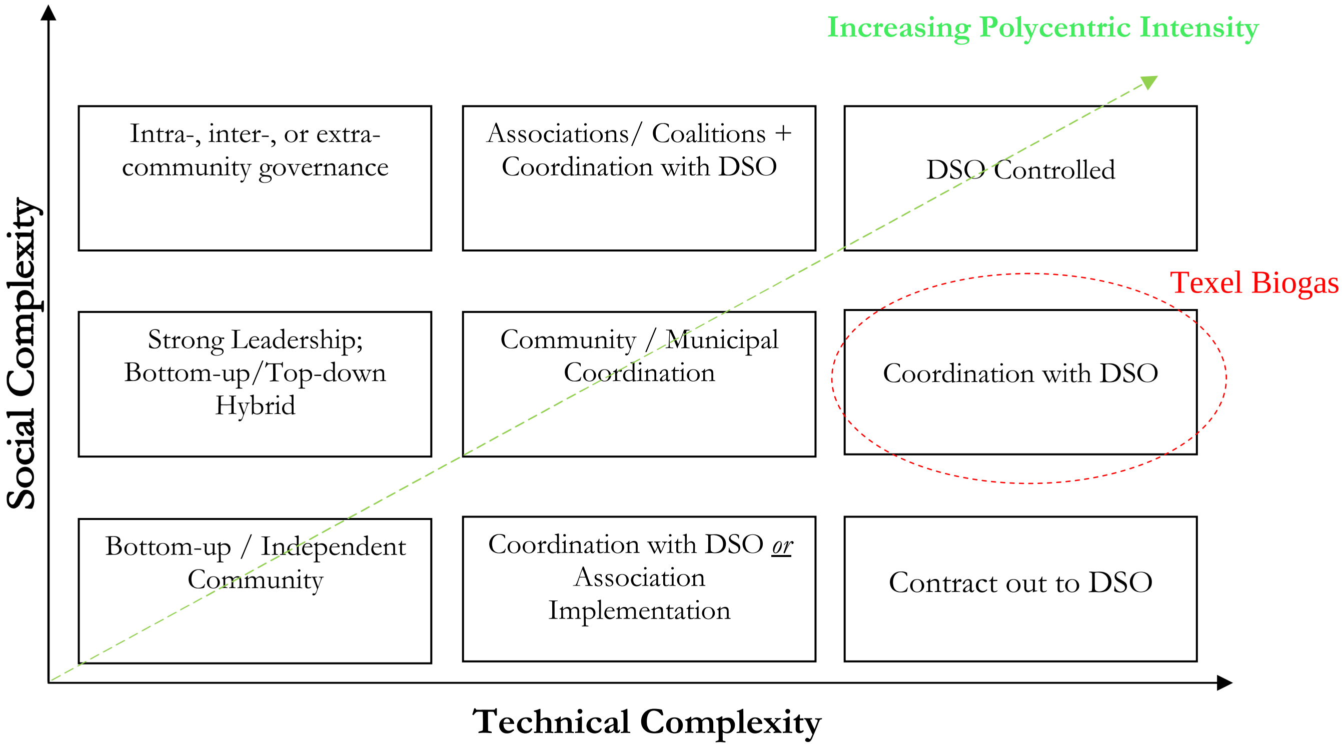
[20] Checking this against the present situation on the island, the theory stands to be at least close to the actual. However, the aims of the islanders go counter-current to what the theory would suggest. A more full case-study of this island is forthcoming.



Matched to the different socio-technical configurations arranged according to varying complexity, are various governance arrangements that are often emergent and local community-oriented in nature (of course, when considering community energy systems), but are at the same time confronted with specific, though sometimes evolving and increasing, technical demands.

The type of self-governance described in each respective box bares the dominant characteristic of that element of coordination. The contents of these boxes are to represent outstanding characteristics of self-governance variations in a given situation. But combinations, accumulations if you will, of different variations of self-governance and governance in general are to be expected, and even nurtured, as multiple spheres of governance become increasingly necessary as complexity increases. This increase in demand for multiple concurrent governance spheres operating in a coordinated fashion is polycentric intensity. It marks the development of governance that is an amalgamation of multiple spheres of governance, each with their own foci and a degree of autonomy, but which share resources and aim to coordinate, check, and balance each other. This is to say that although 'DSO Controlled' (referring back to the last diagram) is written at the top right hand corner, this is not to suggest that at this stage a purely, entirely and solely DSO operated system will exist. Underlying the DSO controlled sphere, which is required, given the demands and constraints the high degree of complexity places upon the operators of the system, there are other spheres that have been developed over time in the development of the system. Associations, coalitions, municipal coordination, contracts, bottom-up neighborhood associations, etc. should be expected to all continue to play a part.

3.3. Revealing Varieties of Self-Governance

Drawing from the stylized and charted community energy systems, as well as from the series of governance options that followed, what becomes vividly clear is that there is an array of arrangements of self-governance in the context of community energy systems. Quite automatically the analysis departs from looking at self-governance v. no self-governance, to arrive at an analysis that begins to open the 'black box' of self-governance. Inside are many varieties, adaptive to the specific surroundings in which it sits. The question of whether or not a community energy system is likely to have self-governance as a robust mode of governance leads to an investigation looking more deeply into what different self-governance arrangements may look like. Indeed, it is this variation and adaptability that gives this local and self-automated governance mode the capacity to be viable in an array of different contexts and stages of developments.

Therefore self-governance itself is suggested to be as variant as its surroundings. It is also adaptive and thereby potentially resilient. We may therefore expect it to be enduring and ubiquitous in local energy systems. Yet, it will not commonly be found in its archetypical form of purely and entirely independent from DSO and ESCOs. On the contrary, many different forms of coordination with the DSOs and ESCOs and associated governing authorities could be anticipated. The Texel case helps demonstrate that even with a well-organized, well-functioning community-based, entrepreneurial-driven energy cooperative, providing a nexus of action, the ability to entirely self-govern a mid-sized community of less than 10,000 homes is only slightly short of impossible. This is a case where the community already has an existing grid at its disposal, already known and operated by the regional DSO. The scenario would be quite different if this was an island putting together a biogas plant without any existing gas network, for instance. The island also confronts legislative issues on multiple levels (former municipal legislation banning local biogas injection, provincial banning of wind farms, national policy push for renewables, regional Wadden island financing mechanism, etc).

4. Reflections

With the framework for assessment of the viability of self-governance in the context of community energy systems outlined, it is time to briefly reflect on some immediate strengths and weaknesses.

The proposed theoretical approach serves well to structure an approach to assessing what degree of compatibility community energy systems, as a whole may have. But the structure also helps to go a step further to demonstrate that the individual local system does need to be looked at on a case by case basis in order to assess its viability. Specific, yet inclusive, parameters have been proposed so that this approach should be applicable to a wide array of local energy systems.

This exercise also reveals that when approaching the question of viability of self-governance, it may be helpful to bear in mind that self-governance itself is an adaptive concept, and an adaptive mode of governance which can vary widely and coordinate flexibly, to fit a given context and its demands.

This happens to be in-line with Elinor Ostrom's findings derived from analyzing governance at a broader level: there are no panaceas to take care of all ailing social systems (Ostrom 2005). The same stands true for the CES array: we cannot propose or expect a single, or even narrowly defined set of governance solutions. Self-governance is a promising option, but it is as variant as it is ubiquitous.

There are also some challenges related to the proposed analytical structure that also merit highlighting. The first glaring challenge lies in the fact that the methodology is 'immature' in the sense that it is largely untested and thinly analyzed in any operationalized level. To see if the theoretical framing can survive a 'reality check' is a first order of business.

Analysis also needs to be deepened to strengthen policy implications which the theoretical framework could elucidate. This also would be expected once more detail is brought aboard. Moving beyond the caricatures of the nine stylized cases to describe these (and others perhaps) socio-technical configurations more in depth should also be pursued.

5. Conclusion

This paper has sought a way to assess the viability of self-governance as a mode of governance in community energy systems. In doing so, we have drawn from insights gained in the socio-ecological system research, where self-governance has already been shown to be often robust. On the other hand, analysis of community energy systems also need to be inclusive of the technical dimensions, highlighted in previous research on socio-technical systems. Although the socio-ecological system framework nicely translated to the socio-technical system context, translating the tools of analysis came up short of operational viability. With these considerations as a background, an approach has been developed to analyze self-governance in community energy systems with a pseudo-rigorous structuring around the two dimensions of social and technical complexity, as variables which can be assessed in terms of increasing and decreasing degrees. This suggested approach has provided a positive, if very modest and initial, step towards applying much thoughtful and revealing research that has been conducted in socio-ecological systems.

Further work needs to be done to further develop field work that tests the framing and hypotheses presented in this paper. Case studies (including Texel Island) are anticipated to further refine what part of the methodology endures further scrutiny. Applications of the theoretical approach developed in this paper toward a dynamic analysis, considering self-governance roles in different stages of community energy systems would also be of interest. This is pertinent due to the fact that many energy systems among communities are in the very early stage of development and often seem to find difficulty in adapting to new challenges; it may be useful to consider the evolution of self-governance roles. Some investigation into how technology itself may simplify complexity (and thereby potentially be an enabler of more potent forms of self-governance) is also an aim for further research, particularly with respect to the involvement of smart meters and grids in local energy systems.

In consideration of transforming and emerging communities who intend to be more proactive with their energy portfolios, regulators and DSOs need to be aware that self-governance is an option and that this option can take different forms with varying degrees of coordination with DSOs and energy service companies. Some degree of anticipation can be tenable that future medium-to-large sized 'decentralized' systems will be neither entirely independent nor entirely dependent (on DSOs, for instance). Rather, polycentric configurations of governance will be likely required, enabling continued local participation but simultaneous to continue DSO and 'regional' governance. It should therefore also be borne in mind by communities, municipalities and regulators that self-governance is likely to be more often than not an insufficient mechanism to adequately govern local energy systems. In many cases, the self-governance which was perhaps there from the beginning will need to be supplemented with other interrelated governance mechanisms in the forms of associations of communities, regional bodies with associated DSOs, etc.

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Abbreviations

CES - Community Energy System

DSO - Distribution system operator

ESCO - Energy Service Company

Annex 1 *Different Stylized Configurations of Community Energy Systems, using biogas as an illustration*

1. Low Technical Complexity / Low Social Complexity
   "Biogas Farmer-to-Neighbor" – This is the most basic form of community[21]. Here, one producer, or most likely, prosumer, has entered into agreement with one other party, a residential neighbor, to supply energy using the prosumer's excess production.

2. Moderate Technical Complexity / Low Social Complexity
   "Biogas Farmer-to-Neighbor (bi-directional)" – Increasing in one degree of technical complexity, the connection between prosumer and neighbor is a bi-directional installation, where one party produces gas via an anaerobic digester, for instance, while the other produces electricity from the PV panels

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[21] Arguably, the family itself would be the basic unit. We have chosen to leave the 'independent energy family' outside the scope of analysis. Moreover, an individual biogas farmer, to borrow the same example used above, could also compress the gas and sell it as fuel as a distributor or retailer, for instance. We have limited our scope of work to community of linked participants via physical energy infrastructure (i.e., not to include those just linked by road or telecom infrastructure).

they have installed on their barn roof. Their agreement is a bi-directional agreement. On the social dimension, no change is made from the previous case, however, the technical complexity increases.

3. <u>Low Technical Complexity / Moderate Social Complexity</u>
   "Biogas farmer to multiple neighbors" – Same prosumer now supplies multiple neighbors, increasing the social complexity of the first scenario, without dramatically increasing the technical complexity of the first scenario.

4. <u>Low Technical Complexity / High Social Complexity</u>
   "Producers-to-multi-community actor groups" – Moreover, the technical complexity may still remain the same, while an additional degree of social complexity is introduced via the introduction of not just multiple individuals but multiple collective actors. These collective actors may possess varying degrees of influence, with heterogeneous interests. These groups may also have different norms established which can suggest increased potential for tension.

5. <u>Moderate Technical Complexity / Moderate Social Complexity</u>
   "Biogas farmer to municipality" – In this instance, one instance could be that the excess heat from the energy production of the farmer may be fed to a municipal swimming pool nearby. This may increase social complexity due to the fact that a whole community is now implicated, even though it is only through one specific venue. This also may represent an increase in technical complexity, though this would depend on the precise community installation.

6. <u>High Technical Complexity / Low Social Complexity</u>
   "Biogas Farmer-to-Natural Gas Network" – At a fairly basic level of social complexity the prosumer may engage a nearby DSO to inject biomethane into the existing natural gas grid. This would be a potentially significant leap in technical complexity, taking the whole process into account of bringing the biogas to sufficient quality standard to meet the technical requirements of the on-spec gas. Pressurization for instance would now be required whereas, local distribution to a neighbor would not need the same degree of pressurization.

7. <u>High Technical Complexity / Moderate Social Complexity</u>
   "Biogas Farmer to community actors + natural gas network" – The same technical difficulty would be coupled with increased social complexity should the farmer also want to locally distribute to community participants while at the same time injecting into the gas grid.

8. <u>Moderate Technical Complexity / High Social Complexity</u>
   "Multiple Prosumers (biogas/wind/solar…) to multiple groups or communities" – Social complexity is increased further still, should multiple types of prosumers be introduced to the energy community. Technical complexity could remain moderate (though it is likely that the technical complexity would bleed into the highly complex category).

9. <u>High Technical Complexity / High Technical Complexity</u>
   "Multiple Prosumers to multi-comm groups + natural gas network" – In this category we have the highest degree of complexity in both dimensions: Here you may multiple layers of participants, formed into different overlapping, potentially conflicting, potentially harmonizing. At the same time multiple different technological capacities are being used in the energy system to coordinate the provision of energy needs among these different individuals and groups, including the general incumbent gas network, which is also a technologically demanding process to access.

Annex 2 *Governance Arrangements for the Respective Stylized Configurations*

1. Low Technical Complexity / Low Social Complexity
   Community Arrangement: "Biogas Farmer-to-Neighbor"
   Governance Form: Bottom-up / Independent Community
   – The form of self-governance in this instance is one of the farmers themselves managing the digestate, digester, localized distribution grid, and all coordination, mutually with neighbor. No involvement from the DSO, and no government regulation is needed, beyond the applicable neighborhood safety laws, etc.

2. Moderate Technical Complexity / Low Social Complexity
   Community Arrangement: "Biogas Farmer-to-Neighbor (bi-directional)"
   Governance Form: DSO *or* Association Implementation
   – As the technical complexity increases, more need for expertise would be in demand. Involvement from the DSO at least for installation purposes may be more necessary, or another third party may be contracted for this purpose. However, at this moderate level of technical complexity, it is possible that for daily operations, local initiatives would still be sufficient. Issues with respect to coordination between participants, conflict resolution, etc. would not be seen as necessitating much extra-community initiative and involvement.

3. Low Technical Complexity / Moderate Social Complexity
   Community Arrangement: "Biogas farmer to multiple neighbors"
   Governance Form: Strong Leadership; Bottom-up/Top-down Hybrid
   – With increased social complexity, the need for the element of leadership arises (Ostrom 2005, Cayford, working documents with Vragender, etc. case studies). Drivers may be more prone to stem from entrepreneurial activity.

4. Low Technical Complexity / High Social Complexity
   Community Arrangement: "Producers-to-multi-community actor groups"
   Governance Form: Intra-, inter-, or extra-community governance
   – With high levels of social complexity, for long-term deliverability, community governance here may be of a less individualistic nature to survive. An individual leader can still be an effective element for the success of the project, but it will probably not be sufficient. Multiple groups, and even communities, with different layers and overlapping and conflicting interest may necessitate 'community governance' where participatory governance within the community leads toward inter-community community coordination. This could be considered a smaller form of polycentric governance, with multiple layers of governance, but all on the community level. Lack of technical demand, and no far-reaching scope of influence continues to allow for safely governed independent community arrangement.

5. Moderate Technical Complexity / Moderate Social Complexity
   Community Arrangement: "Biogas farmer to municipality"
   Governance Form: Community / Municipal Coordination
   -Using the example of a farmer whose residual heat (from independent power production used for lighting a greenhouse) is fed into a nearby municipal swimming pool, there arises the clear need for

municipal representation to be involved, albeit such involvement may not need to exceed that of normal banal tasks and decisions of public building maintenance and operations.

6. High Technical Complexity / Low Social Complexity
   Community Arrangement: "Biogas Farmer-to-Natural Gas Network"
   Governance Form: Contract out to DSO
   – In this instance, the DSO will be obliged to insure that the gas being distributed in their grid is of on-spec quality. It would be potentially very costly for the DSO if damaging particulates were admitted into the network, or if safety issues were compromised, such as odorisation. It is therefore in the interest of the DSO to be involved intimately in the upgrading process of the biogas, to biomethane. At the same time, the farmer does lacks the expertise that the DSO possesses, and will therefore carry the incentive to contract out the upgrading to the DSO.

7. High Technical Complexity / Moderate Social Complexity
   Community Arrangement: "Biogas Farmer to community actors + natural gas network"
   Governance Form: Coordinated with DSO
   – The same technical difficulty would be coupled with increased social complexity should the farmer also want to locally distribute to community participants while at the same time injecting into the gas grid. This would require additional community involvement, while maintaining coordination with the DSO. Here it will most likely be critical for the DSO to be on-board as an involved community-party, to garner the trust and support of other community members to insure safety issues, in receiving gas from the 'farmer Joe' neighbor.

8. Moderate Technical Complexity / High Social Complexity
   Community Arrangement: "Multiple Prosumers (biogas/wind/solar…) to multiple groups or communities"
   Governance Form: Coalition & Association implementation & Coordination with DSO
   – Coalitions and Associations can be a critical mainstay for community-governance robustness. This is more surely the case with increased social complexity, coinciding with a significant degree of necessary technical expertise. Organized representation of various interests can be crucial in preventing debilitating impediments in the social system. Further, technical associations can assist in increasing efficiency and effectiveness in handling technical issues locally, and in coordination with the DSO, without complete reliance or outsourcing to the DSO.

9. High Technical Complexity / High Technical Complexity
   Community Arrangement: "Multiple Prosumers to multi-comm groups + natural gas network"
   Governance Form: DSO Controlled operations, community-prescribed initiatives
   – With the far-reaching scope of broad community involvement coupled with full technical engagement at the highest level, the option of leaving the full chain of responsibility within the community provision, remains a viable option. This would not negate community involvement in terms of initiatives, and the implementation from the side of granting rights for the renewable options to be installed, etc. But it would be a situation in which the full responsibility of the entire community network would ultimately be in the hands of the DSO.