Investigating the peculiarities of sustainable energy policies in islands communities for smart grid development: insights from complexity science and agent based models

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Investigating the peculiarities of islands communities for smart grid development : insights from complexity science and agent based models

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Abstract

Initiatives and projects ranging from European islands to the Falklands and the Pacific Fiji islands are implementing renewable energy sources. They not only address the unique features of islands but also to reduce the economic vulnerability of small island states and in some cases, regenerate depopulated island communities and enhance socio-economic and ecological sustainability.

Islands are often regarded as laboratories for, or precursors of, wider energy transitions and the “smart grid” innovation makes no exception. The “smart grid” is an umbrella term that covers modernization of both the transmission and active distribution grids and the different competing smart grid architectures could transform the electricity industry and the relations with consumers and prosumers.

This paper asks two – relatively simple – questions: are there any socio-technical energy systems and dominant designs more prone to emerge depending on the topologies and scale of islands? How far can we learn and scale up lessons from the studies of island energy communities that are useful in other Complex Adaptive Systems (CAS) with greater scale and interconnectivity?

This exploratory paper is part of on-going research project (CASCADE) to model smart grids as Agent Based Systems embracing concepts and techniques from Complexity Science. There are three key objectives.

The paper initially summarizes the key particuliarities of island energy systems, including the scale and boundaries to the socio-technical system that combine to determine the appropriateness of different energy responses, balancing and optimizing the various combinations of distributed renewable generation, energy storage (including plug-in cars), and loads.

From this, a provisional conceptual model will be presented which identifies the range of factors that (re)configure to influence the potential dissemination of new energy technologies within island communities and the range of agents that influence that process.

The paper will build on an expanding literature on modelling societal transitions with cognitive agents and agent transformation to justify our modelling choices. Central to the question is how to represent the cognitive agents and their adoption of new technologies and adaptation patterns.Validation may benefit from data from the Bornholm smartgrid case and other case studies.

Keywords : Smart grids, sustainable energy islands, Agent Based Models, societal transitions

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1 – Introduction

Islands are excellent case studies for the concept of sustainability, and to show the value of systems thinking. For Rasmussen (2010), several present island-societies, and amongst them Danish islands, contain possibilities to develop a significant change in how sustainability is to be understood in a broader as well as in a deeper sense.

Sustainable energy policies for islands have not only to address the unique features of islands (scale, fragile environment, strong dependence on conventional resources, high power generation costs, energy weight within the GDP, abundance of renewable energy sources) but also to reduce the economic vulnerability of small island states by reducing the usage of increasingly expensive, imported fossil fuels. Renewable energy is a very good candidate in most islands. Indeed, in addition to solar, hydro, wind, biomass and biogas, oceans—through currents, tides, waves, and thermal and salinity gradients—offer a source of new renewable forms of energy that remains underexplored.

That transition to more sustainable electricity generation needs to occur is effectively beyond question; however there are many questions which remain to be answered. The different pathways for such a transition are a fertile area for research activity. We will first introduce the literature on this subject. In particular, in addition to regime shifts, pathways are also dependent upon the communities in which they occur, the pre-existing connectivities, policy decisions, resource availability. Therefore, we will focus on some peculiarities of small island energy systems and report on some insights provided by on-going case studies[1]. We are interested in understanding how community initiatives play a key role in establishing and reinforcing positive social norms and engaging and educating individuals through - existing or re-created - trusted relationships.

We propose in this paper an approach to model behaviours of agents and simulate transitions in the small scale island energy sector. Indeed, The CASCADE project aims is to reveal, classify and explicate the complex system behaviours, entities and reconfigurations that may emerge from the interactions of heterogeneous agents at multiple scales, based on the premise that the legacy electricity market will become increasingly decentralised through the massive penetration of smart grid technologies and distributed energy.

We intend to learn, compare and scale up lessons from the studies of island energy communities that are useful in other Complex Adaptive Systems (CAS) with bigger scale and different interconnectivity.

2 – Socio technical transitions in energy systems

Sociotechnical transitions

The term socio-technical transition has been used to describe the transition of a Socio-Technical System (STS) from one regime of operation to another. In turn, an STS may be quite generally defined as the linkages between elements required to achieve a societal goal.

This paper considers socio-technical transitions proposed by Kemp & Rip (1998) in the light of the Multi-Layer Perspective (MLP), developed by Geels (Geels 2002, 2004, 2005, 2010). This framework[2] explicitly considers that societal systems comprise inter-locking economic social, cultural, economic and technical sub systems and accounts for transitions at different rates within different levels (Bergman *et al*, 2008). The three levels detailed in figure 1 provide different kinds of coordination and structuration of activities in local practices. According to Geels (2002, 2005), the relationship between the three concepts can be understood as a nested hierarchy, meaning that regimes are embedded within landscapes and niches within regimes.

In the energy sector, the STS concept and approach is used to explain energy transitions, historically and prospectively, notably by Verbong & Geels (2007) in the Netherlands or to understand pathways

1 The development of the Islands within the context of European Cohesion Policy (EUROISLANDS) http://www.espon.eu/main/Menu_Projects/Menu_TargetedAnalyses/EUROISLANDS.html

For an overview of relevant activities and best practices, see the European Islands Network on Energy and Environment – ISLENET, a network of European Island Authorities, http://www.islenet.net

2 The concept is widely used and discussed for example Markard and Truffer (2008) bringing in innovation systems), Elizabeth Shove and Gordon Walker (2007) bringing in constructivist and practice-theory sensibilities; Audley Genus and Anne-Marie Coles (2008) bringing in actor network theory), Andy Stirling, Frans Berkhout and Smith (2005; bringing in constructivist and political science issues. In 2010 special issue of research policy (Smith, Grin & Voss), Geels enhance the reflexivity in transition debates regarding social theories. To that end, the article discusses seven social science ontologies (rational choice, evolution theory, structuralism, interpretivism, functionalism, conflict and power struggle, relationism), their assumptions on agency and causal mechanisms, and their views on socio-technical transitions and environmental sustainability.

for a low carbon electricity system (Foxon, Hammond & Pearson, 2010). Recently, there has been a focus on scale and geography (Smith, 2009).

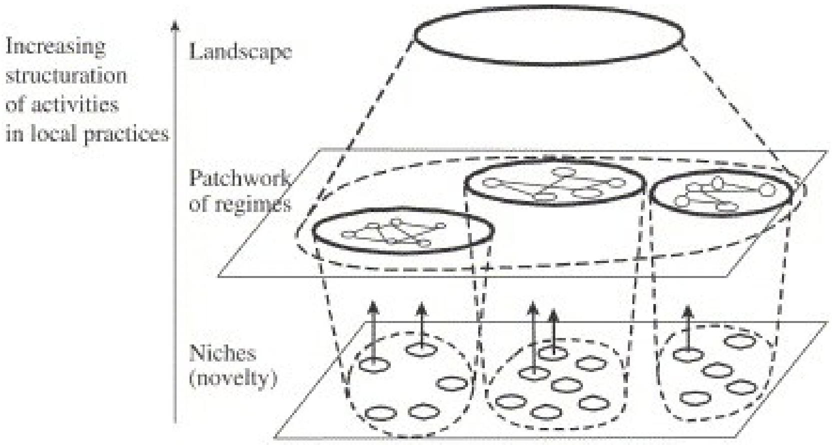

Figure 1 : Multiple levels as a nested hierarchy (Geels, 2002, p. 1261).

Niches are important, because they provide locations for learning processes. Learning processes occur on many dimensions, e.g., technology, user preferences, regulation, symbolic meaning, infrastructure, and production systems. In the following section, we introduce competing visions and expectations and anticipations of agents in smart grids.

Transitions in the electricity sector: visions for Smarter grids

Electric grids are complex systems and to some extent already smart, but the vision is to make them smarter to allow for a wide range of innovation. Various definitions of smart(er) grid(s) coexist. We will rely on the definition of a smart grid by the EU Technology Platform SmartGrids[3], which defines smart grids as "*electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies*".

Islands are often regarded as laboratories or precursor of wider energy transitions and many new smart grids projects are being developed in islands. The smart grid describes a re-configuration of the electricity grid to incorporate communication links alongside the traditional power supply links, artificially intelligent devices and dynamic management of the grid. One of the goals of such a smart grid is to actively manage the load on the grid in order to smooth demand and to allow for intermittent renewable energy production.

Figure 2 : EPRI visions

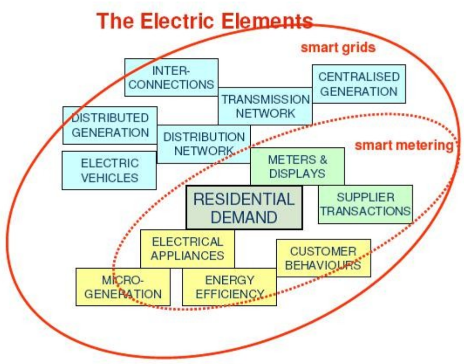

Figure 3 : smart grids elements from the European Technology Platform

3 The European Electricity Grid Initiative (EEGI) Roadmap 2010-18 and Implementation Plan 2010-12, have been prepared by ENTSO-E and EDSO-SG in close collaboration with the European Commission, ERGEG and other relevant stakeholders. www.smartgrids.eu

As well as the technical challenges, there are many social issues to be addressed in the transition to, and successful adoption of, a smart grid.

Socio-technical transitions needs mobilisation,ownership and to build on active demand

It is widely acknowledged that the transition to smart(er) grids inevitably requires a 'knowledge transition' among various actor groups to enable them to better understand the available technical, pricing and policy options. In particular, there is a need for stakeholders' networks able to sustain projects through their full cycle, uniting promoters, users, utilities, Energy Service Companies (ESCOs), SMEs, technicians, banks, local authorities. A main hypothesis is that studying prosumers and emerging low carbon communities as a context of individual behavioural change is critical.

Recent literature on public awareness and behavioural change has suggested that more focus should be placed on the community level. For example, the EU "Changing Behaviour" research project analyses different types of emerging low-carbon communities as a context for individual behavioural change. The focus is on how these communities offer solutions to problems in previous attempts to change individual behaviour. These problems include social dilemmas, social conventions, socio-technical infrastructures and the helplessness and disempowerment of individuals (Heiskanen *et al*, in press).

Mobilisation of citizens is of particular importance to reduce load peaks and promote energy efficiency.

Research on energy communities tends to concentrate on one aspect of the social dimension, the "acceptance of renewable energy technology", its definition and measurement. We are more interested in how communities can engage in designing solutions and in particular in active demand.

Active demand[4] is a generic term to develop technical solutions both at the consumers' premises and at the power system level to enable active demand and to allow real-time response to requests from markets and/or other power system participants. Therefore the new innovations focus on:

- Interaction through real-time price and volume signals,
- A new approach (the "Demand Approach") to foster the flexibility and active participation of consumers,
- Distributed intelligence and local optimization

In addition to the peculiarities of the island energy systems that we will address in the following paragraphs, one of the open questions to our investigation is whether island communities present special characteristics related to social conventions. Unlike large industrial customers, domestic customers are not motivated purely by economic considerations. Islanders may also present special behaviors and more ownership of the vision to a more sustainable energy system. We will come back to those issues at the end of the paper. They may also be inherently better suited for certains types of technologies and business models.

Factors influencing future dominant designs: do islands benefit from competitive advantage?

Innovations in an emerging field, like the smart grid, create different alternative solutions and opportunities for existing and new firms and industries. At some point architecture becomes accepted as the industry standard. Dominant designs may not be better than other designs in the market place, however they will incorporate a minimum required set of key features. This notion of dominant design (Abernathy and Utterback, 1978; Gort and Klepper, 1982; Suarez, 2004) has received attention in organization theory and in industrial organization and has stimulated empirical investigation over the past three decades.

The transition to the smarter grid concept is a restructuring of the electricity sector and there remain large technical and organizational questions. Many questions do not have ready answers: What are the effects of higher or lower proportions of variable demand on the evolution of technology required in the electricity grid? What are the effects of introducing micro generation and / or active demand in large quantity to the grid? Are there "tipping points" in terms of quantity of various elements (e.g. electric vehicles - EVs - for storage, smart houses etc) required to enable smart grid management? At what scale can self-sufficient microgrids emerge? How will the technical system (i.e. the grid itself) change to meet the demands of the more distributed system as a whole? What intermediate term transition effects emerge that may be undesirable (e.g. system overloading by introducing "green" technologies such as heat pumps and EVs before the grid and active demand management are capable of supporting them)?

4 See for example the ADDRESS FP7 EU research project standing for -"Active Distribution networks with full integration of Demand and distributed energy RESourceS".

Those questions may have different answers in different contexts. In the last section, we will present the CASCADE project which aim is to investigate those questions. A first step is to understand a small system. Therefore, we focus now on small island electric networks and their peculiarities.

3 – Peculiarities of islands energy systems

An island grid is more sensitive to external factors (Mayer, 2000), and it cannot always rely on interconnections with neighboring networks. Island networks intensify technical challenges of grid operation and peaks may be more sudden and difficult to manage. Island energy and electricity systems are particular - one might attempt to formulate typologies of islands energy systems even if contexts, economic development and vulnerabilities are different (Guerassimof *et al*, 2008). The European Insular Areas Typology identifies and systematically categorises the different types of renewable enegry use that are appropriate for remote, ecologically sensitive island areas[5].

Most of the attention so far has indeed been on the generation side. In the following paragraph, we focus on the peculiarities of islands when facing the implementation of the smart grids concept. We choose to focus on: stability and economics of the small grid, storage issues, potential of active demand and identity.

Grid stability and economics

Isolated small-sized electricity systems present a series of characteristics that complicate and raise the costs of electricity supply. The generation units cannot be too big as the loss of one generator would have a large effect on the overall system. This means that economies of scale cannot be adequately exploited on the same level as in the large electricity systems (Mayer, 2000). It also makes the technical management of the network more complicated with regard to frequency and voltage. Isolation also makes it necessary to maintain more reserve capacity to ensure adequate supply, meaning they cannot take advantage of the possibilities inherent in interconnected electricity systems, which generate greater stability in a system (Perez & Real, 2008).

Weisser (2004) examined the main problems faced by electricity systems in small, isolated island systems, the most important of which is that electricity supply in these territories is also more expensive because there are high fuel transmission costs. However, the main conclusion from Kayser-Bril et al. (2008) concerning power generation is that renewables are now more cost effective than diesel gensets for small capacities in an island context.

Electricity storage

Storage issues are high on the research agenda as storage is one of the ways to deal with intermittent sources and variable load. Electricity is inherently difficult and expensive to store and amongst the existing solutions (such as different types of batteries, heat storage, compressed air, flywheel), pumping water into a reservoir when demand is low are the easysiest and cheapest solutions. However, for territories which do not have hydro reservoirs, hydrogen solution is studied in various island locations (Krajic, 2008, 2009) with planning tools for storage, such as H2RES for H2 storage modelling.

Companies are researching the possible use of Electric Vehicles for meeting peak demand. A parked and plugged-in EV can sell the electricity from the battery during peak loads and charge either during night (at home) or during off-peak. Islands are seen as good laboratory for diffusion demonstration projects such as in Bornholm with the EDISON project or La Reunion with Projet VERT (Electric Vehicle for Technology-wise Reunion).

Most of the existing study on islands investigated the generation side. However, understanding energy demand and responses from consumers to change in pricing or adoption of new technologies is particularly important in small smart grids.

Patterns of electricity consumption

Studying reasons for different patterns of electricity and energy consumption in islands is beyond the scope of this paper. More details would be available from case studies[6]. However, we wanted to provide a comparison (figure 3) of the Isles of Scilly and the large scale UK system.

5 RERINA EU project, http://www.rerina.net/?secid=7. Deliverables include a presentation of the results of the implementation of the proposed methodological approach, i.e. the typology, including information for four insular areas Armenous, Cabras, Aphodite Hills (Cyprus), a Sicily area

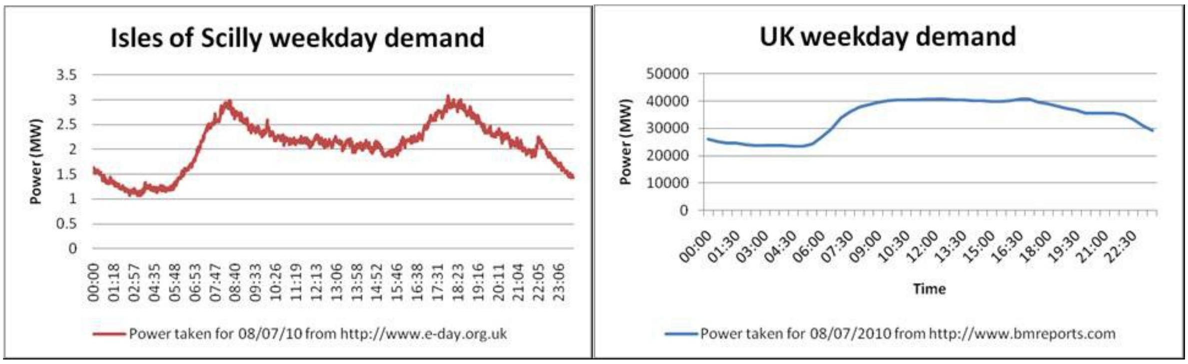

Figure 3: Typical summer day consumption in Isles of Scilly and the bigger UK system.

It can be seen that the demand profile for a small island group (in this case the Scilly Islands) shows some marked differences from a larger grid (in this case the UK). Particular features in addition to the obvious differences in scale of demand are the “sharper” peaks in demand around 0800 and 1730 with a noticeable dip between these demands. In contrast the larger grid in effect “smoothes” demand between these two traditional peaks. There may be a number of reasons for this – some peculiar to a small island scenario, for instance a lower proportion of industrial / commercial demand leading to the overall demand more closely following a typical residential pattern.

Our modelling approach will have the facility to take explicit account of such differing features of grids on different scales.

Identity of islanders and sustainable energy communities

Issues of ownership and identity must be considered when examining measures to encourage local generation and demand reduction/smoothing. Small islands in particular show an interesting dilemma with regard to identity (Stuart, 2008). On the one hand, small islands wish to preserve their unique culture and identity, which leads to a desire to preserve the status quo. On the other hand, in energy terms, preservation of the status quo often means perpetuating a reliance upon large mainland corporations or metropolitan authorities to supply energy either as electricity via interconnection or raw fuel. This relationship often gives large energy companies ownership of infrastructure and control over strategic decisions, local employment and tariffs. With regard to renewable energy generation on small islands, Stuart notes that this dilemma has led to patchy adoption without support from a powerful champion within the small island jurisdiction (Stuart, 2006). To realise the full benefits of smart grid technology on islands, then, it is clear that this dilemma needs to be addressed. Stakeholder engagement at all levels is crucial to enable energy efficiency and adoption of renewable and small scale generation whilst remaining aware of the need to preserve individual islands’ identity. The pre-disposition to maintain the status quo is consistent with findings that small islands tend to lag behind in terms of technical efficiency (Domah, 2002).

Initiatives are committed to diverse targets, from 100% renewable islands, like Samso, El Hierro, to developing Local Sustainable Energy Action Plans for islands and ecologically sensitive areas with the aim of meeting or exceeding the EU sustainability targets of 20/20/20 for the year 2020[7]. The need to strengthen community approach is acknowledged, especially throught the Sustainable Energy Communities (SEC) scheme and European Commission fundings in Europe. Indeed, value, vision and policies by the government much differ from those of public and local communities.

In the following section, we will detail some smart grid demonstration projects.

4 – Presentations of ongoing smart grids deployment case studies

There has been a strong interest in renewable energy technologies for European islands (Chen *et al.*, 2007), Small Islands Development States (SIDS), or overseas territories envisaging sustainable energy strategies for islands (Bertarelli & Rynikiewicz, 2008). There are also a few case of Smart

6 For Bornholm, one could refer to “Security of supply for Bornholm : Integration of fluctuating generation using coordinated control of demand and wind turbines”. Demand side options for system reserves, Ea Energy Analyses, 2007, http://www.ea-energianalyse.dk/reports/640_Security_of_supply_for_Bornholm.pdf visited May, 17th, 2010

7 Currently there are 12 participating groups of European Islands (over 60 islands) involved in the project ISLE-PACT, see http://www.europeanislands.net/?secid=3&pid=64&spid=106& (accessed june, 10th, 2010)

Grids deployment in islands: Malta, Orkney, Bornholm, to mention a few of the small scale islands but also smart grids in New Zealand (Nair & Zhang, 2009) Taiwan, or Ireland.

Integrated case study

Bornholm is an island situated in the Baltic Sea. With respect to area, electricity demand and population Bornholm corresponds to approx. 1% of Denmark. Electrically Bornholm is only connected to the mainland power grid through a sea cable to Sweden. This gives a possibility of running in island mode, giving unique possibilities of studying the power grid (including the impact of electric vehicles). Bornholm also has a high share of wind energy in the consumed power; in 2008 the share was approximately 30 %. This makes Bornholm a small model of the expected society of Denmark year 2020, where Denmark is committed to reach an amount of 30 % renewable energy.

Moreover, the vision of Bornholm as a green island includes the goals of becoming 100% based on renewable energy (Jayakrishna *et al.*, 20), utilization of Bornholm as an experimental facility for the future energy system and creation of green job and development on the island. The strategy is branded under the label “Bright Green Island”.

Østergaard and Nielsen (2010) provide an overview of the Bornholm power system. Østkraft is the distribution system operator supplying electricity to about 28,300 customers at Bornholm. Of these 302 (1.08%) consumers have a yearly demand above 100,000 kWh which accunts for about for approximately 30% of the load. The peak load was 56 MW in 2007.

Orkney is a case where smart grid concepts at the distribution level have already been employed and new generation connected to the grid. This has altered the dynamics of the island in terms of power to be self sufficient in terms of electricity generation, reduced dependence on interconnection to the mainland and enhanced economic ability to sell electricity back to the mainland grid.

Outside Europe, Korea is deploying a Smart Grid Test-bed in Jeju Island for 6000 households. Wind farms and four distribution lines are included in the integrated pilot program.

Case studies of integration of large quantities of renewable energy

There are a growing number of studies on the integration of large scale or important quantities of renewable, intermittent energy sources (Smith *et al*, 2008) both in continental grids and islands.

Ireland (peak load ~ 6,000 MW) is a special case for large scale penetration of RES as the potential of RES is larger than the prospects for consumption. The All Island Grid Study addressed wind generation in Ireland, its accommodation by the transmission system and grid reinforcement.

Demand load management and motivations

Load management is particularly interesting to reduce the peaks on the electricity network, by balancing the supply of electricity on the network with the electrical load by adjusting or controlling the load rather than the power station output. Special tariffs are designed to influence consumer behavior.

There also a number of initiatives that builds on the cosmopolitan values and biospheric values (De Groot & Steg, 2008) of islanders.

For example, the Isles of Scilly (off the coast of Cornwall) Earth Summit (3-4 October, 2009) is a good example amongst others where international, national, and local islanders talked about the impact of climate change and human activity on their island. It was the first co-ordinated attempt by a community to reduce their electricity use and to have the effects of their efforts measured in real-time.

Storage device are also a way for smoothing power fluctuations from renewable resources especially wind power and provide valuable system services for a reliable power system operation. The Danish government’s energy strategy implies 50% wind power penetration in the electric power system. In Bornholm, the study integration of wind energy (Chandrashekhara *et al.,* 2010) was carried out considering the Danish electricity network state around 2025, when the electric vehicles penetration levels would be significant enough to have an impact on the power system. Management of charging is important for more reasons. One reason is the risk of increasing the early evening peak load if vehicles are simply plugged in and charged as soon as arriving home after work. Another reason is that the battery capacity of the vehicles is a necessary aid for making integration of more wind energy possible without endangering the stability of power supply or having to sell power in the spot market to very low prices.

EDISON[8] project for EVs in Bornholm

The Danish EDISON project has been launched to investigate how a large fleet of electric vehicles (EVs) can be integrated in a way that supports the electric grid while benefitting both the individual car owners and society as a whole through reductions in CO_2 emissions. The consortium partners include energy companies, technology suppliers and research laboratories and institutes. The aim is to perform a thorough investigation of the challenges and opportunities of EVs and then to deliver a technical platform that can be demonstrated on the Danish island of Bornholm. The preliminary research will be used to conduct field tests on Bornholm in early summer 2011 with duration of approximately 6 months. It should be sufficient to fully proof that the developed technologies will be one of the solutions when charging of a large percentage of electric vehicles has to be managed.

Acceptation and appropriation of new technologies

They are very few specific studies on values of islanders related to energy technologies or emergence of new behaviours. Very recently, Sherry-Brennan, Devine-Wright & Devine-Wright (2010) explored the role of values in the social representation of hydrogen energy in the context of a community-owned wind–hydrogen energy project in the Shetlands. Whilst the content of individuals' basic values were the same as the universal structure of values, variations found were considered to be culturally-specific.

We have previously identified a wide range of factors influence the potential dissemination of new energy technologies within island communities and the range of agents, local and otherwise; human that influence that process. In the next paragraph, we will explain which insights can be gained from complexity science and Agent based Modeling tools, and the newly launched CASCADE project.

4 – Insights provided by the CASCADE Project: focus on Complex Adaptive Systems and intelligent agents

Electricity networks can be classified as Complex Adaptive System and the CASCADE[9] project ambition is to study Complex Adaptive Systems, Cognitive Agents and Distributed Energy.

The adaptivity of a system emerges from the behavior of agents within that system and the interaction between those agents. The collective structures and/or characteristics of the system cannot be determined from the characteristics and behaviours of the individual agents. This then leads to a requirement for a modeling framework within which to study such a CAS. This framework is provided by Agent Based Modeling (ABM)[10]. As noted by Schilperoord *et al* (2008), ABMs are uniquely suited to modeling transitions, with the ability to study the transition processes in themselves, rather than an equilibriumist approach of treating transition as simply a move between two (possibly dynamic) equilibria.

ABMs also allow easy integration of heterogeneous actor behaviour – allowing the facility so study questions such as - "Are the actors different on an island? How are the agent behaviours determined by cultural norms?" - without fundamentally changing the model.

The CASCADE project seeks to also consider the retail market and the effect of introducing large amounts of distributed generation into the network.

We are effectively exposing the erstwhile consumer to the wholesale market as a producer or *prosumer* – a term coined by Alvin Toffler in his 1984 book "the Third Wave"[11] and more recently adopted to describe end users as both consumers and producers of electricity (Mauri *et al.,* 2009). In addition, the project will introduce automated agents into the model rather than modeling only

8 E.D.I.S.O.N. is an abbreviation for "Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks". The EDISON project is an international research project partly publicly funded through the Danish transmission system operator (TSO) Energinet.dk's research programme FORSKEL.

9 CASCADE : a Complexity Science-Based Investigation into the Smart Grid Concept see, http://gow.epsrc.ac.uk/ViewGrant.aspx?GrantRef=EP/G059969/1

10 A number of projects have used ABM to model electricity grids, such as EMCAS and AMES in America; NEMSIM in Australia and PowerACE in Europe . However these models have been primarily focused on examining the economic effects of wholesale market liberalization, sometimes with consideration of CO2 emissions also (in the cases of NEMSIM and PowerACE).

11 A. Toffler. The Third Wave, Bantam Books, New York (1980).

corporate and individuals as agents. This introduction of "intelligent" automated agents is fundamental to the smart grid concept.[12]

Following the emergent literature and powerful tool of ABM, we wish to identify the range of factors that (re)configure to influence the potential dissemination of new energy technologies within island communities and the range of agents, local and otherwise; human that influence that process. Those agents will be incorporated in a provisional conceptual model.

Heterogeneous agents, consumers and prosumers

The CASCADE project aims to introduce a wide variety of heterogeneous agents into a testbed and study the emergent effects of renewable energy introduction and agents interaction. Agents to be represented in the model include:

- **Generators**
- **Suppliers**
- **System Operators**
- **Legislators/regulators**
- **Householders (of various kind)**
- **Storage agents (at varying scale with varying technologies such as hydrogen cell, Electric Vehicles (EV), hydro-electric storage)**
- **Smart appliances within households (automated active demand agents)**
- **Smart distributed generators at household and/or community scale (automated active demand agents)**

The strategies that each of these agents employs for learning and decision making will be studied, drawing on an expanding literature.

Moreover, behaviours of a wide range of consumers will be differentiated at different timescales. In particular, the phenomenon of "behavioural lock in" in energy consumption, highlighted by Marechal (2010), calls for looking at habits and routines and not only at the consumer as a rational agent. More studies highlighted the social and psychological aspects of using Load Management on the Grid with intermittent power generation are needed as studied by Devine-Wright, P. (2003). In addition, theories of consumer behaviour and specifically consumer behaviour with regard to innovation, sustainable consumption, transition and renewable technology adoption will inform more structural changes.

Nye, Whitmarsh and Foxon (2010) explore the active roles that domestic consumers might play in different transition pathways to a lower carbon electricity economy. They reviewed psychological and sociological perspectives on the drivers for everyday energy-use patterns, situating these in the context of the body of research on transitions in sociotechnical systems. We will mobilize their proposed social-science-based framework, for analysing the active ways in which domestic actors might facilitate or support the transition to a lower carbon economy. In addition, agents will learn from their experience.

Learning agents

In addition, different adaptive learning techniques have been applied to different agents within the Multi-Layer Perspective (MLP) framework as implemented by Schilperoord *et al.* (2008). The appropriate representation of different learning and decision making processes for different agent types will be determined. The effects of different representations on the model outcomes and transition behaviour will be studied and reported in a future paper.

With these agents acting in the system, the prospect of Demand Side Management (DSM) as a technique to smooth demand (i.e. reduce variability) becomes a real possibility. The techniques required to achieve this remain a fertile area for applied research, however the benefits of a robust technique to perform DSM are well understood.

This approach to modelling transition will give insight into the changes required to enable sustainable electricity provision. Island case studies will be fundamental to the determination of different approaches required to deliver secure and reliable generation from sustainable technology in different environmental and socio-technical landscapes. The modelling of different technologies as active demand agents will enable the model to test which technology is the appropriate technology for a given scenario.

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12 As per http://www.smartgrids.eu/?q=node/163 -'*A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies'*

Bulk energy conservation and CO_2 emissions will be monitored and compared to Business as Usual (BaU) scenarios in order to understand and quantify the benefits of the smart grid.

5 – Conclusions and future research

The smart grid or smarter grid concept is challenging the conventional grid approach and in turn will alter social, economic and technological connectivities both within an island and between islands and other communities. Island case studies, with their specific peculiarities as described above in section 2, offer unique opportunities to model and study real world scenarios.

This paper builds on an expanding literature trying to design novel approaches to modelling transition to a sustainable electricity generation system. The new CASCADE project will contribute to the issue of modelling the socio technical transitions. The modelling will benefit from previous pioneering work by Schilperoord *et al.* (2008) who propose different adaptive learning techniques as well as other ABM (Agent Based Models) experiences.

This paper has confirmed the interest in simulating this transition which is novel within the electricity sector. It has also outlined the way in which such an approach is applicable to islands and how lessons could be learnt from a diversity of island case studies which can inform our understanding of the transition to a smart grid. In turn, the transition will benefit island communities as they have reduced dependence on connectivities to others either via direct electricity import or fossil fuel imports. Smart grids are likely to also improve dependability of supply in territories where that is an issue

There remains much further work to do. Hopefully, Island case studies will provide some insights on how peculiarities of (low carbon) island communities regarding values, social dilemmas, social conventions may shape differently the smart grids of the future.

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