2014 ASIA-PACIFIC SOLAR RESEARCH CONFERENCE

paper ID # + Andrew Peacock

Autarkic Energy Systems: Balancing Supply And Demand with Energy Storage and Controls in Local Energy Micro-grids

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Stream: CRC for Low Carbon Living and IEA Solar Heating & Cooling: Cities and communities

When visioning for best possible future energy systems in a world with growing populations, limited fossil fuel resources, rising energy prices and less energy security - more individuals, communities and cities are looking to utilise autarkic principles to harvest, store and optimise use of local energy resources. Energy autarky can be described as *a location that relies on its own energy resources for generating the useful energy required to sustain the society within that region* or *a situation in which a region does not import substantial amounts of energy resources*. Functioning autarkic energy systems typically require a micro-grid, well understood energy demand and supply characteristics, opportunities for energy storage of various types and controls able to manage the harmonisation of system components. A critical additional ingredient is users who can work within constraints created by the adoption of autarkic principles. To elaborate the challenges and explore the issues involved with autarkic energy concepts this paper reports on the output from a workshop convened to investigate the role that energy autarky might play in delivering societies able to deliver the ambitious renewable generation targets set by both Scottish and UK Governments. In addition, monitored data from a community micro-grid system in Northern Scotland is analysed and presented to provide additional understanding of the complexities and opportunities created by an autarkic approach. The output from the workshop identified that whilst it is probable that a dogmatic interpretation of energy autarkic will not be universally applicable, the underlying principles represent a bottom up way of widening participation in the development of future energy provision models. Whilst a number of issues and barriers were raised regarding its adoption, the attendees recognised that energy autarky represented a very positive and empowering vision for translating global scale issues to local energy transition. The analysis of monitored generation and demand data from a community micro-grid underlined the problems associated with supply-demand matching with intermittent generation and the need to place an emphasis on the community or entity as an open system that is able to participate in a full range of trading opportunities. Similarities were found between the types of behaviour necessary to create load responses relevant to energy networks containing large penetrations of renewable generation and communities set up along energy autarkic principles.

1. Introduction

There are a rising set of socio-political circumstances and trends that are challenging the hegemony of incumbent energy provision models; prominent among these are energy security, climate change, resource depletion and a loss of faith in the capacity of centralised institutions, beholden to the primacy of shareholder value to provide democratised provision of energy. Allied to these factors is the rapid technological change being delivered in the fields of energy generation and communications that is creating economic opportunities for different visions of provision at radically different scales.

Scenario analysis conducted by the GB electricity transmission system operator forecasted that the proportion of installed generating capacity provided by embedded renewables would grow from a figure of circa 9% in 2010 to a figure of between 16 and 23% by 2030 depending on the scenario chosen (National Grid, 2012). The realization of these forecasts, broadly seen as necessary if the UK is to meet its national targets and international obligations will require a change in the way power networks are configured, and controlled. The transition from the existing top down, predict and provide models to some form of distributed control approach has been widely predicted (Peacock and Owen, 2013). This transition will necessitate a change in relationship between all actors in the energy supply chain; between the generator, the distributor, the retailer and the consumer with the demarcation between these groupings becoming increasingly blurred.

One emergent set of principles that may have the potential to provide a framework that addresses these socio-technical shifts is energy autarky. Energy autarky is variously described as *a location that relies on its own energy resources for generating the useful energy required to sustain the society within that region* (Muller et al., 2011) or *a situation in which a region does not import substantial amounts of energy resources* (Schmidt et al., 2012). The concept of energy autarky is not new but it has been gaining in prominence as a consequence of the factors listed above. For instance, 57 citations were found in Google Scholar for the term “energy autarky” before the year 2000, 98 between 2000 and 2010 and 214 already this decade. A number of issues abound with a dogmatic interpretation of energy autarky, for instance;

- how are boundaries defined and should embodied energy be included
- neo-classical trade theory suggests resultant reduction in trade would manifest itself as higher commodity and transaction costs
- security and resilience of energy supply may be impaired
- significant jeopardy of some regions experiencing transitional lock-out as a consequence of the approach not being universally applicable

These difficulties have led to a series of interpretations of the concept with variety further stimulated by it being an emergent paradigm that has not yet been subjected to efforts of standardization (Hansson, 2010). For instance an entity may be described as *energy neutral* whereby it generates more energy locally than it consumes and trades the surplus (Rae & Bradley, 2012); it may be described as *net zero carbon* (Sartori et al., 2012) that can be taken to mean that it produces surplus carbon free energy that it can trade to offset its consumption of carbon based energy; it can be described as *stand-alone* meaning that the energy it produces locally is sufficient to meet its needs although this definition can still permit the trade of forms of energy e.g. purchasing diesel for stand by generators.

A pragmatic version of energy autarky is used here describing the formation of an organising entity(s) whose role is to characterise energy demand for the local economy and services and to subsequently source this requirement from energy services derived from predominately locally renewable energy resources. In essence it will seek to create a supply condition that minimizes the use of imported fossil fuel based resources and maximize in its stead the probable use of local resources (Figure 1). This definition effectively acknowledges the economic certainties that the imposition of a more dogmatic definition of energy autarky would result in a significant increase in costs and a likely diminution in service (Krajačić et al., 2010). Effectively this definition uses autarky to describe a destination that the entity may never reach but that will be used to determine its transitional direction.

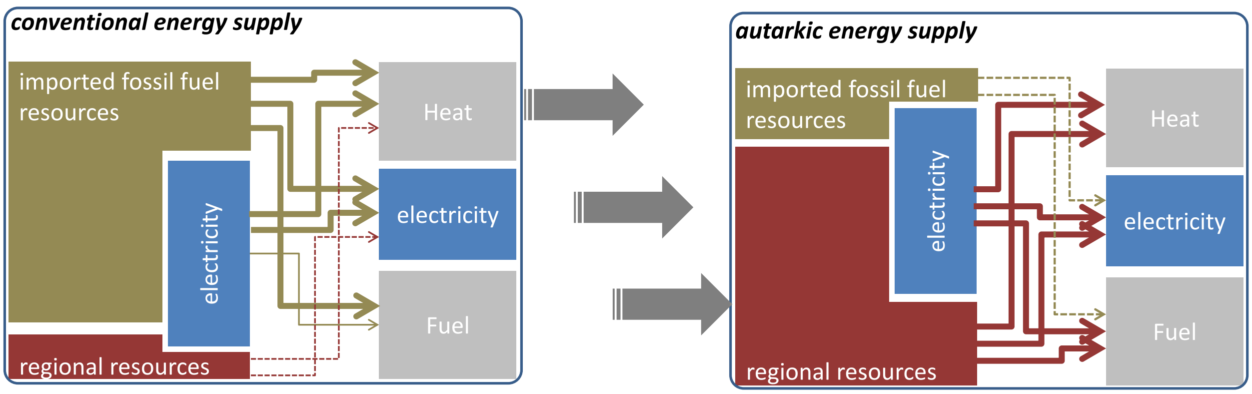

Figure 1: Pragmatic autarky – transition to an autarkic energy supply motivated by a desire to reduce imported fossil fuel resources to a defined region or community

The definition applied here, places an emphasis on the entity as an open system that is capable of participating in a full range of trading opportunities (Figure 2). This introduces the possibility of the entity creating value from managing energy demand and local supply in such a manner as to benefit wider societal efforts with respect to national and international obligations. Energy autarky as described then could represent a way in which participation in the ensuing energy transition can be broadened to encompass more actors than merely the owners of generating systems or the land on which they are deployed.

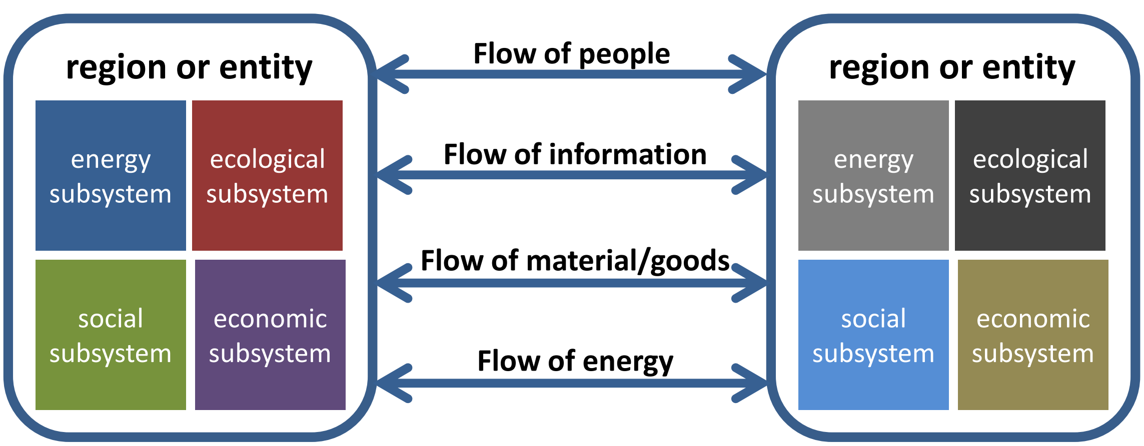

Figure 2: Pragmatic autarky – regional boundaries and trading arrangements

This paper uses two approaches to explore autarkic concepts in more detail. In the first instance it reports on the output from a recent workshop involving energy practitioners and academics (ICARB, 2014) that sought to describe social, economic and technical pathways that would allow Scotland to meet its governmental pledge to reduce 2050 carbon emissions by at least 80% from 1990 levels (Scottish Govt, 2010). One pathway that was explored was the adoption and promotion of autarkic energy systems. In the second instance, monitored generation and demand data from the Findhorn Foundation Community was analysed to provide additional understanding of the complexities and opportunities created by an autarkic approach

2. Autarky Workshop

The key outcomes from the workshop are listed below but a core realization was that in effect many UK organisations are developing their own energy systems in ways that are in essence underpinned by autarkic principles. These included cities, communities, hospitals, schools, landed estates and land owning organisations such as the Forestry Commission as well as energy and water utilities. Through a series of interactive exercises based around the backcasting principal (Quist, 2006) the following core findings regarding the energy autarky vision emerged:

- It was seen as being very positive and empowering for translating global scale issues to local energy transition
- It very firmly placed agency in the hands of the people creating more dynamic activity, local job creation and long term sustainability for communities
- It had the potential to provide substantial societal benefits, reduced sense of isolation and lack of connectivity and helping to may help to bind communities through heightened social interaction
- Implementing the autarkic vision in urban settings where the majority of the population live would present greater challenges than in rural settings
- A number of economic issues would have to be addressed; namely issues about who would pay for grid connectivity, localised energy generation may actually increase costs, how start-up capital could be attracted and how autarkic approaches might have an impact on the wider economy and country wide GDP
- A range of issues were highlighted as being critical, namely; energy efficiency and retrofitting was key, development of system integration knowledge was critical, potential for DC grids, heat and power system should be championed, twinning urban areas with rural to allow renewable energy technologies to be correctly situated but allow urban areas to benefit economically; local autarky champions would have to be created.

The workshop participants recognised that the principal disruptive influence was likely to be cultural in dimension through the creation of new entrants into the energy market (e.g. local utilities, Consumer Co-op', Housing Associations trading in energy). These new entrants may seek to exploit technology and communications advances to create change in energy provision to support a desire for more local/regional solutions.

3. ORIGIN Project

3.1. Introduction

In the ORIGIN project a sophisticated ICT system for the management of energy in a community has been developed and is being deployed based on the concepts of aligning energy demand with the availability of renewables-based supply, addressing community goals with respect to cost, carbon footprint and other objectives. The hardware of the system comprises energy monitoring systems in buildings, actuators for selected devices, cloud based storage of data, and an associated communications infrastructure. At a temporal resolution of 30 minutes, the ORIGIN demand response architecture delivers the following; a) 48 hour ahead forecast of renewable generation, b) 48 hour forecast local demand, c) quantified forecast of surplus generation, d) identify a series of load shifting opportunities and e) optimise the sequencing of these opportunities to produce a demand response schedule (Figure 3). The overarching aim is to increase the proportion of renewable generation that is used locally and minimise the imports of energy to the community. Electricity, heat and transport energy vectors are included in the study which involves three communities; the Findhorn Foundation Community in Northern Scotland, the Damanhur community in Piedmont, Italy and the Tamera Healing Biotope in Southern Portugal.

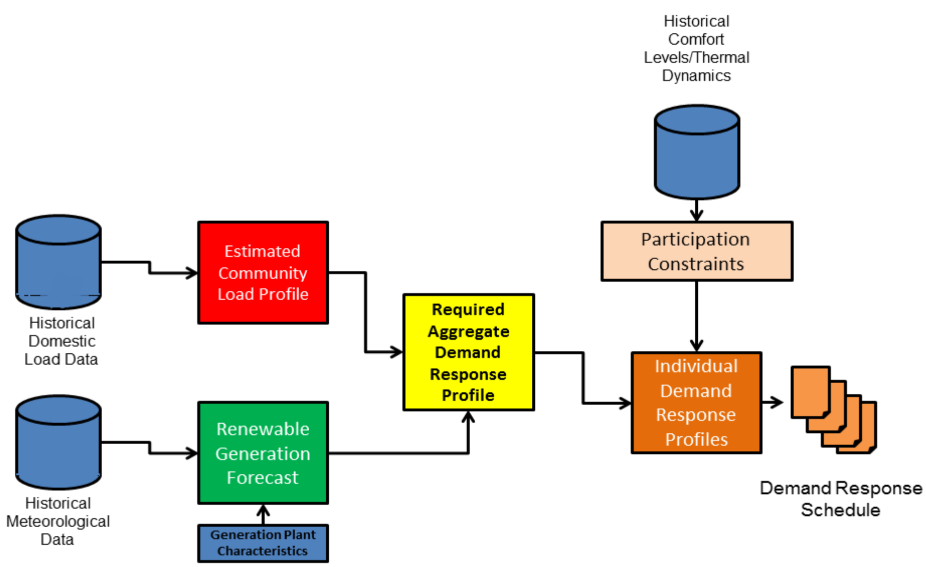

Figure 3: ORIGIN system demand response architecture

To elaborate upon the challenges and explore the issues involved one of the three communities included in the ORIGIN project is considered, namely the Findhorn Foundation Community in Northern Scotland. The community owns and operates a mixture of renewable energy generation technologies and energy provision infrastructure including wind and solar-PV installations, a low voltage electricity distribution grid, an energy retailer and three distinct hydronic district heating systems fed by biomass boilers (Table 1).

Table 1: Description of key attributes of the Findhorn Foundation community energy systems

Location	Northern Scotland
Number of buildings	Circa 130
Installed solar-PV	25kW
Installed wind generation	750kW
Biomass district heating system	650kW
Total installed capacity of air source heat pumps	75kW
Total installed area of solar water heating systems	Circa 100m^2
Electricity distribution network	Private wire; grid connected

3.2. Supply demand matching

The issues associated with achieving supply demand matching are illustrated by considering the production of renewable generated electricity from the community wind farm and the rooftop solar-PV systems in comparison with community electrical demand for the period 23rd to the 29th March 2014 (Figure 4). The total demand for this period was 6640kWh of which 30% was imported from the national grid despite the total renewable generation for the week being 21,843kWh. Renewable electricity was generated almost entirely from the wind park with 79% being exported to the grid. This is not an atypical result and alludes to the issues associated with accommodating large capacities of renewable generation into existing grid infrastructure, designed over time to manage variability only with respect to load.

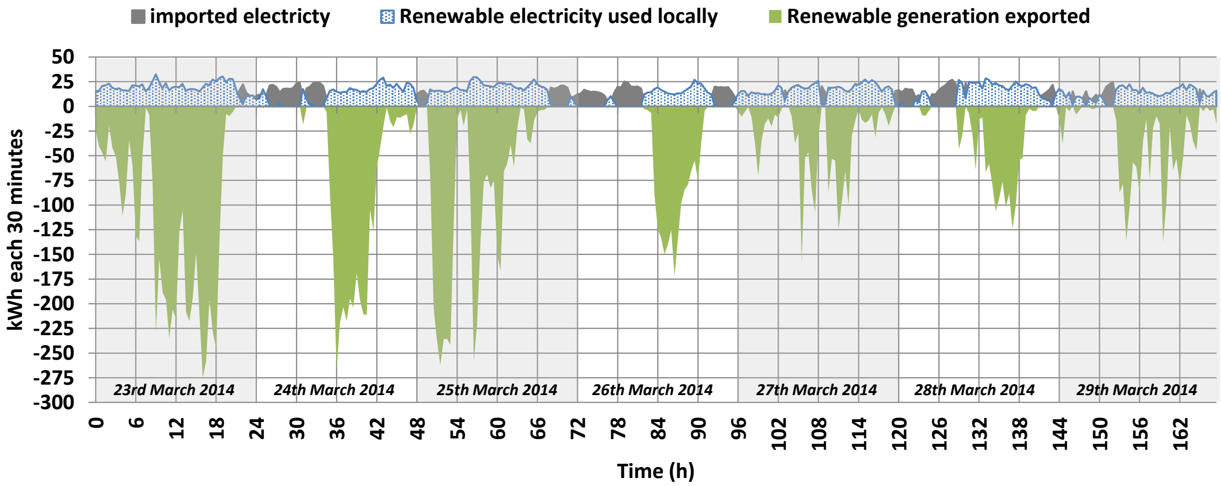

Figure 4: Supply demand matching of renewable generation with local demand

The issue of timing of export becomes critical and the results from a full calendar year reveal variation with time of day and with season with winter, as expected, yielding higher capacity factors for wind generation and therefore higher levels of export from the community to the grid (Figure 4). Peak export periods are during the afternoon, reflecting the predominant thermally induced wind regime in the UK. The value of the exported electricity to the operators of the national grid varies with time of day, currently in response to load variability, i.e. export is more valuable during peak demand periods than it is during the middle of the night. However, as the penetrations of renewable generation on the grid increase creating significant supply side variability, the value of export may become less associated with time of day and more associated with prevailing patterns of renewable availability. A community that is able to manipulate its load profile in response to forecasts of renewable surplus may be creating a commodity whose value can be traded with the operators of the energy systems across different scales and geographical horizons. This illustrates the need to view autarkic systems as a series of connected entities that have the capacity to trade surpluses both between entities if plausible and with the incumbent centralised systems. The trading arrangements may yield the potential for communities that do not have access to either capital or to the land to participate in the ensuing energy transition through behavioural change to manipulate their load profile to help absorb supply side variability, democratizing participation and allowing wider societal aspects such as fuel poverty to be addressed.

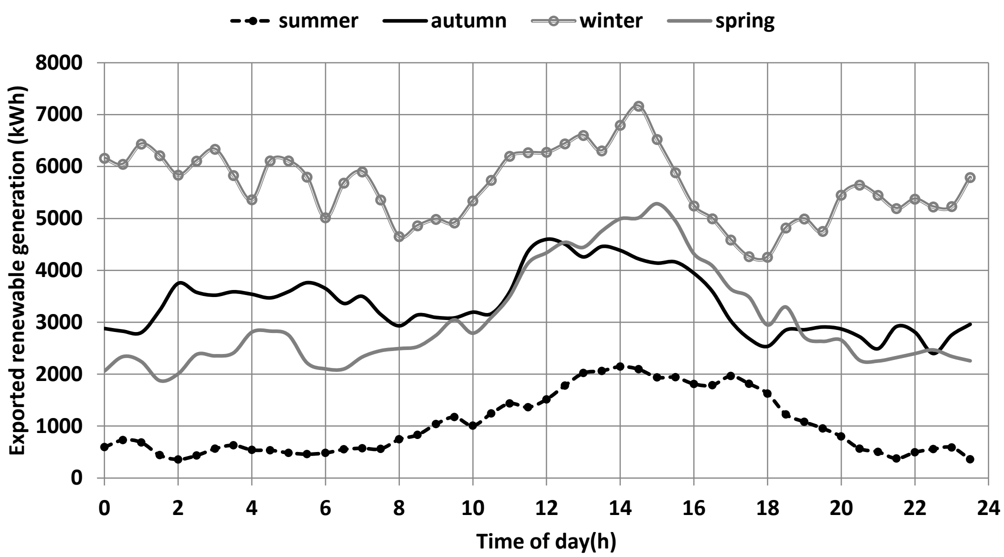

Figure 4: Electrical export from the Findhorn Foundation Community to the national grid disaggregated by season and time of day

3.3. Further work

The ORIGIN project will seek to explore the boundaries of behavioural change both through informational systems and through direct actuation of consumer loads. With informational systems the forecasts of surplus will be provided to the community participants up to 48 hours in advance and will be contextualised to make it relevant to the recipient. Electrical heating systems, buffered through thermal stores will be actuated directly based on the surplus forecast information to allow the resultant loads to better match to renewable generation. Overall the aim is to increase the proportion of locally generated renewable generation that is used locally.

4. Conclusions and discussion

The achievement of true energy autarky is unlikely in all but the most specific of circumstances. However, its principles may become valuable in creating societal entities that can contribute locally towards the achievement of national and global energy policy aims. In the example provided, the Findhorn Foundation Community are participating in a project to explore ways in which loads can be manipulated via behavioural change and direct actuation to move the community closer towards autarkic principles. In so doing it is entirely feasible that they create a commodity, i.e. firm and predictable load profiles, that is of value to electricity network operators who are seeking to accommodate nationally driven capacities of renewable generation. The transition stimulated by the investigation of energy autarky by the community may alight upon behavioural change with respect to the timing of energy use and its relationship to intermittent renewable generation that may be of national and possibly global significance. The ORIGIN project will deploy the demand response software in autumn 2014 and will be reporting on the impact it has on the three communities from spring 2015.

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Acknowledgements

The authors would like to thanks the Findhorn Foundation for their participation in the ORIGIN project and for ICARB for the organisation and delivery of the workshop