Orchestration of Renewable Integrated Generation in Neighbourhoods

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D5.7 Evaluation of ORIGIN Outcomes and Full Potential

WP5 – Deployment & validation of the ORIGIN energy control and orchestration algorithm

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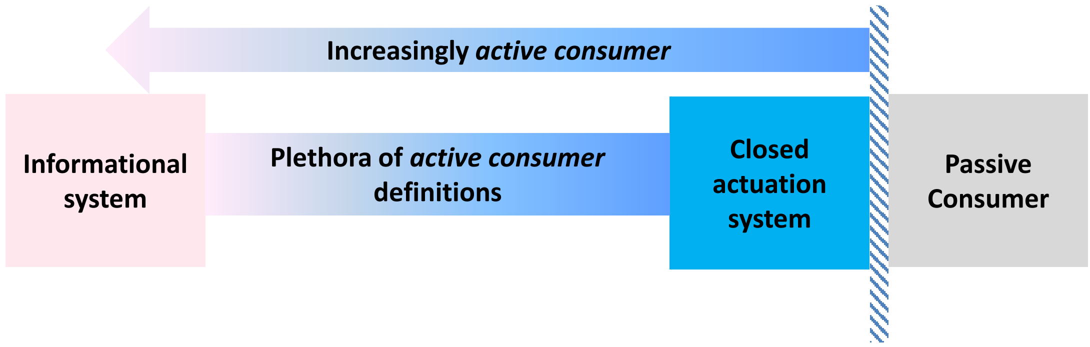
1. Introduction

A critical feature of all built environment demand response programmes is the extent of participation required of consumers in order that its objectives are achieved. The current electricity network is managed almost entirely without recourse to consumer participation. In the main the consumer is entirely passive, manipulating plug loads, space conditioning and domestic hot water (DHW) systems with no constraint with respect to time or load. The smart grid approach, widely advocated as a vital component of future energy networks envisages that consumers will undergo a transition that will see them play a more active role in grid management (Figure 1). The opportunities that emerge over the next two decades stimulated by financial incentives, technological solutions and changes in social norms will determine the scale of the transition.

Figure 1: Boundaries of active consumer participation in a demand response system



At one end of this scale is an entirely actuated system whereby the targeted load is the recipient of the information exchange. This could be viewed as being closest to the current passive paradigm. In this closed, actuated system, ownership of the control and assumptions that cause load manipulation rests with the system controller and although the occupant will have oversight, they do not need any transient perception that a transaction is taking place. The benefits of direct actuation are that the impact of demand response can be quantified and is firm.

At the other extreme is an informational system that contains no actuation. Here, participants are informed of future events, are cognisant of the implications of their response and decide whether to act based on the information received. Informational systems are either based on incentives (tariff changes) or are essentially feedback systems where some other type of motivational data is conveyed to participants. They could be installed in dwellings without the requirement for sensing and actuation equipment and without the requirement for there to be a range of smart appliances. Clearly an informational system does not create the same level of technical risk associated with actuated systems but social acceptability issues may arise particularly where modified tariff structures are imposed. However social acceptability issues resulting from the loss of personal energy control through the deployment of actuated systems may also create political tensions.

The research team considered the energy networks, systems, built environment infrastructure and community ethos found at each pilot site in determining the type of demand response system that was most appropriate. The outcome of these deliberations was that a mixture of demand response approaches were applied (table 1).

Community	Demand response project	Type of response
Damanhur	1. Building electricity demand	Informational - feedback
Tamera	2. Improved micro-grid control	Quasi-actuated
Tamera	3. Electric Vehicle Charging	Actuated
Findhorn	4. Household electrical demand	Informational – incentivised
Findhorn	5. Household thermal demand	Actuated
Findhorn	6. Washing machine demand	Informational - incentivised
Findhorn	7. Community electrical demand	Informational - incentivised & feedback

Table 1: Type of demand response programmes initiated in each community

The objective function of each of these approaches, or projects, was to increase the utilisation of locally generated renewable energy with the secondary function of reducing imported energy. This report quantifies, for each demand response project, the extent to which this occurred. This report is structured as follows; each demand response project is reported in four sections. The first section provides an overview of the project often with reference to other deliverables where it is described in more detail. The second section describes the measured impact. The third suggests which elements of the overall ORIGIN architecture were required to deliver the impact and the fourth section provides a commentary of the wider national/EU market applicability of the project.

2. Demand Response Projects

2.1 Damanhur - Building Electricity Demand - Type of Response: Informational - feedback

Description

The ORIGIN system was installed in three buildings in the Damanhur community; namely Magilla, Cornucopia and Dendera. These were communal residential buildings housing between 17 and 25 people. The space heating and hot water requirements of each of these buildings were supplied by biomass boilers augmented with solar thermal systems. The buildings did not have mechanical cooling systems. Each building had solar PV panels installed on the roof with Magilla having the highest capacity of 27kW compared to 3.0 and 3.5kW in Cornucopia and Dendera respectively.

The small capacity of the PV arrays installed in the Cornucopia and Dendera buildings in comparison to their consumption levels resulted in all of their output being used in the dwelling. For instance, during the week commencing 5th July 2015, whilst PV output was at or near its peak, Dendera average building daily demand was 2.8kW with peak demands of 9.1kW. This compared with average output of 0.64 and peak output of 1.5kW from the PV arrays. In contrast, in Magilla electricity was exported from the PV array to the grid on 92% of the days between March and

November 2014, i.e. when PV output was low. The Magilla building was used to establish whether the ORIGIN system had altered the energy practices of the building occupants.

A key finding of the ORIGIN project has been the critical importance of community engagement when developing, deploying and maintaining novel energy network systems. This was borne out in Damanhur where the local ORIGIN champion left the community in year three. This created a vacuum for a period before alternative measures were successfully arranged in early May 2015. This community engagement issue straddled the deployment of the ORIGIN system. Its impact was considered within the overall impact of the ORIGIN system by creating three datasets:

a) A benchmark dataset covering the period May to November 2014 which describes energy practices in Magilla before the ORIGIN system was launched (notation BM)

b) A data set covering the period March to May 2015 which describes energy practices after the launch of the system but when no local champion existed (notation MM)

c) A data set covering the period June to October 2015 which describes energy practices when the system was in place and the engagement strategy was back on track supported by the local energy champion (notation JO)

The principal factor that was found to determine the quantity of renewable electricity utilised by the building was found to be the total output from the PV system. Its pervasive influence necessitated that these datasets had to be constructed to ensure equivalent PV output. This was determined by testing the hypothesis *the population medians were equal*. A non-parametric analysis of variance test (Kruskal-Wallis) was used as the daily PV output in each of the datasets were found not to be normally distributed (Table 2). The test statistic (H) had a p-value of 0.84, both unadjusted and adjusted for ties, indicating that the null hypothesis can be accepted. Any variance found between the datasets in the amount of renewable electricity used in Magilla is therefore likely to have been caused by factors other than PV output.

Dataset	N	Median (kWh per day)	Ave Rank	Z
BM	123	76.30	219.0	0.42
MM	92	78.40	209.1	-0.52
JO	214	74.11	215.3	0.04
H = 0.34 DF = 2 **P = 0.84**				
H = 0.34 DF = 2 **P = 0.84** (adjusted for ties)				

Table 2: Kruskal-Wallis test for median daily PV generation for each dataset

Impact

The proportion of electricity generated by the PV systems in Magilla for each time period was compared, again using the Kruskal-Wallis test (table 3). The results indicated a small but significant increase (3.0% compared to BM) in the proportionate consumption of PV generation in the JO dataset. This increase was not found in the MM dataset, the critical difference perhaps being the absence of a local champion.

Dataset	N	Median E_{used} (%)	Ave Rank	Z
BM	123	63.4	179.4	-3.77
MM	92	63.9	207.4	-0.66
JO	214	66.4	238.8	3.96
H = 18.37 DF = 2 **P = 0.00**				
H = 18.37 DF = 2 **P = 0.00** (adjusted for ties)				

Table 3: Kruskal-Wallis test for median proportion of PV generation used in Magilla

- The total electricity generated for the period described by the JO dataset was 14,905kWh for the JO dataset.
- Assuming BM behaviour would have resulted in 9,450kWh of the total electricity generated by the PV system being used in Magilla compared with 9,897kWh, the figure actually observed
- This is an increase in utilisation of 447kWh
- This would save 184kgCO_2 at the household level[1]
- The annual output from the PV array in Magilla (to October 2015) was 30.3MWh (10.8% capacity factor). Assuming that the level of response displayed between June and October was replicated over the whole year, the annual increase in self-consumption of PV output would be 910kWh resulting in a reduction of 374kgCO_2e pa attributable to the dwelling.

Product/Service description

The ORIGIN forecasting algorithms coupled with the ORIGIN User Interface (UI) was used to deliver this service to the occupiers of building that have integrated solar-PV systems. Information could be contextualised for building occupiers using the statistical clustering approach described in D6.4 and using the occupancy sensing algorithms described in D6.3.

Market

The total installed capacity of solar-PV in the EU reached 88.4GW in 2014[2]. The overwhelming majority of this is in building integrated systems. In the UK, for instance the total number of domestic roof top solar-PV systems exceeded 1M in 2014[3]. Whilst the growth in additional PV capacity in the EU is slowing, there are regional/national markets where installed capacity has a significant impact on grid management. At a national scale these are Germany, Italy and Spain with installed capacities in 2014 of 35, 18 and 5GW respectively. These markets could be described as early adopters for products and services that would increase self-consumption of PV production in buildings with integrated systems.

[1] Assuming a grid emission factor of 0.411kgCO_2/kWh for Italian grid electricity and zero CO_2 emissions assigned to the PV panels
[2] Jagel-Walden A., (2014), PV Status Report 2014, JRC Science and Policy reports, European Commission
[3] Professor Sue Roaf, private communication

2.2 Tamera – improved micro-grid control - Type of response: Quasi-actuated

Description

Each of the pilot sites represented a distinct challenge when it came to the design of demand response projects. The situation presented by Tamera was particularly challenging with two aspects of the community being distinctive. Firstly, household scale demand response is extremely limited in Tamera due to a number of factors that include:

(a) Extremely low electricity consumption levels; the average electricity consumption per person per day was 1.5kWh in 2013 compared to a Portuguese average of 3.7kWh.
(b) The community ethos eschews personal ownership and this extends to habitable space. The concept of households does not therefore exist in Tamera
(c) Individuals are not responsible for paying their own bills with energy consumption being paid for centrally as a community good

Secondly, the Tamera community are anomalous with respect to the other two pilot sites in that they have a connection contract with the national grid operator that does not permit them to export electricity. The consequence of this is that all of the PV that is generated in Tamera is used by the community. The issue that the community faces is that in the absence of storage capacity, when output from the PV array exceeds local demand it is curtailed. This is explained in greater detail in D5.5.

A modelling exercise was carried out using Tamera energy network data and community electrical demand for the period 7th to 13th July 2014 (described in more detail in D6.1). A statistical relationship was derived between PV output, irradiance and temperature during periods where PV output was not curtailed. This relationship was then applied to the entire dataset to estimate the amount of PV output that was being curtailed, i.e. was in effect surplus.

A procedure was designed that utilised this modelling approach to create forecasts of PV surplus for the following day at 16h00 today. This procedure was carried out by the research team and communicated to the Tamera technical group on a daily basis by e-mail as part of a limited field trial. The intention was that they would then take actions to eliminate or mitigate the forecasted curtailment. Whilst these could include load shifting behaviour it was expected that they would predominantly involve changing the way in which the battery charge and discharge cycles were controlled to ensure capacity was available when surplus electricity was being produced. The undesirable but, up to the involvement of ORIGIN, alternative was that the battery system was charged from the grid during the night, thus ensuring full batteries in the morning and preventing storage of PV generation.

Impact

A) Modelled Results

Alternative control strategies for grid import and battery charge/discharge cycling were defined and explored. The model suggested that 55kW of PV could be accommodated with the existing energy infrastructure without curtailment. The model also suggested that the annual amount of PV output curtailed in the Tamera micro-grid was 13.5MWh. Improving control methodology to utilise this curtailed power would be equivalent to an increase in capacity of 7.0kW of PV in Tamera. Assuming a cost of €1,700 per kWp installed this equates to a capital cost of €11,900. The reduction in bills would range from €1,300 to €2,800 pa depending on the time of day that the stored surplus electricity was subsequently re-used.

B) Field Trial Results

Initial findings from the limited field trial that was conducted between October and November 2015 suggested that knowledge gaps existed regarding control modification of the inverter. The existing strategy, whilst not optimal from the perspective of PV output has been in operation for a number of years during which time no outages have been recorded. Moving to an alternative control strategy is non-trivial as it may result in outages occurring, particularly during the night. The procedure for forecasting PV surplus has been documented and transferred to the Tamera technical group who will continue to use it to increase their understanding of their micro-grid such that they can optimise its control.

Product/system description

The ORIGIN forecasting architecture capable of providing localised renewable and demand forecasts was utilised to provide this demand response service. The system could be wrapped into existing control systems, e.g. off-grid inverters such as the SMA Sunny Island 5048 (as used in Tamera). Alternatively it could be bought as a stand-alone system used to determine demand response initiatives. The forecast horizon could be extended to 72 hours to assist in planning demand response (see D4.7).

Market

The Tamera energy network complies with conventional definitions of a micro-grid, i.e. a localised grouping of small-scale generating units, energy storage, and loads that normally operates connected to a traditional centralised grid, but is capable of self-islanding and working as an autarkic system.

Total global generation from micro-grids that comply with this definition has been estimated as being 3.5GW in 2012[4], an increase of 2.2GW since 2009[5]. The sectors represented include industrial complexes, military complexes, University Campuses, remote off-grid systems and community systems. These latter two categories are most appropriate for ORIGIN systems and are comprised of circa 1.5GW of the 3.5GW total in 2014. The average project size of the remote off-grid system was

[4] BSRIA (2014), file:///C:/Users/adp30/Downloads/Microgridexecsummary.pdf accessed Nov 2015
[5] http://www.navigantresearch.com/wordpress/wp-content/uploads/2010/12/MICRO-10-Executive-Summary.pdf accessed November 2015

estimated as 100kW, which if applied to both criteria would result in a total addressable market of 15,000 systems.

2.3 Tamera –Electric Vehicle (EV) charging - Type of response - actuated

Description

The research team organised and facilitated a co-design workshop in Tamera in May 2015. The objective was to produce a methodology that would allow EV charging stations to be actuated to increase the coincidence of their use with PV generation particularly during curtailment periods. Community members developed and set criteria for the key priorities of the charging unit and the logic by which it operate. These were interpreted by the research team to produce a flow chart that informed the subsequent production of software (Figure 2).

Prototype hardware systems were developed and installed at each charging station in Tamera. System readiness was established in test trialling in November 2015. The Tamera community will be field trialling the system during the first quarter of 2016.

Impact

Tamera operates 10 electric vehicles that each travel an average of 15km per day. The technical potential for load shifting through car charging was estimated, based on data obtained from test trialling the prototype systems, to be circa 20kWh, with a peak load of 3.5kW. This is greater than 10% of the peak output from Tamera's PV array system and would therefore be capable of a highly significant contribution towards curtailment mitigation strategies.

Product service

The software system utilises end to end ORIGIN architecture as there are multiple charging stations and vehicles. Orchestrating the needs of the individual vehicles with improved matching of supply and demand as defined by the forecasts is therefore required.

The ORIGIN team, led by the Tamera Community designed the prototype hardware systems. These may have applicability in other applications, e.g. in similar community micro-grids.

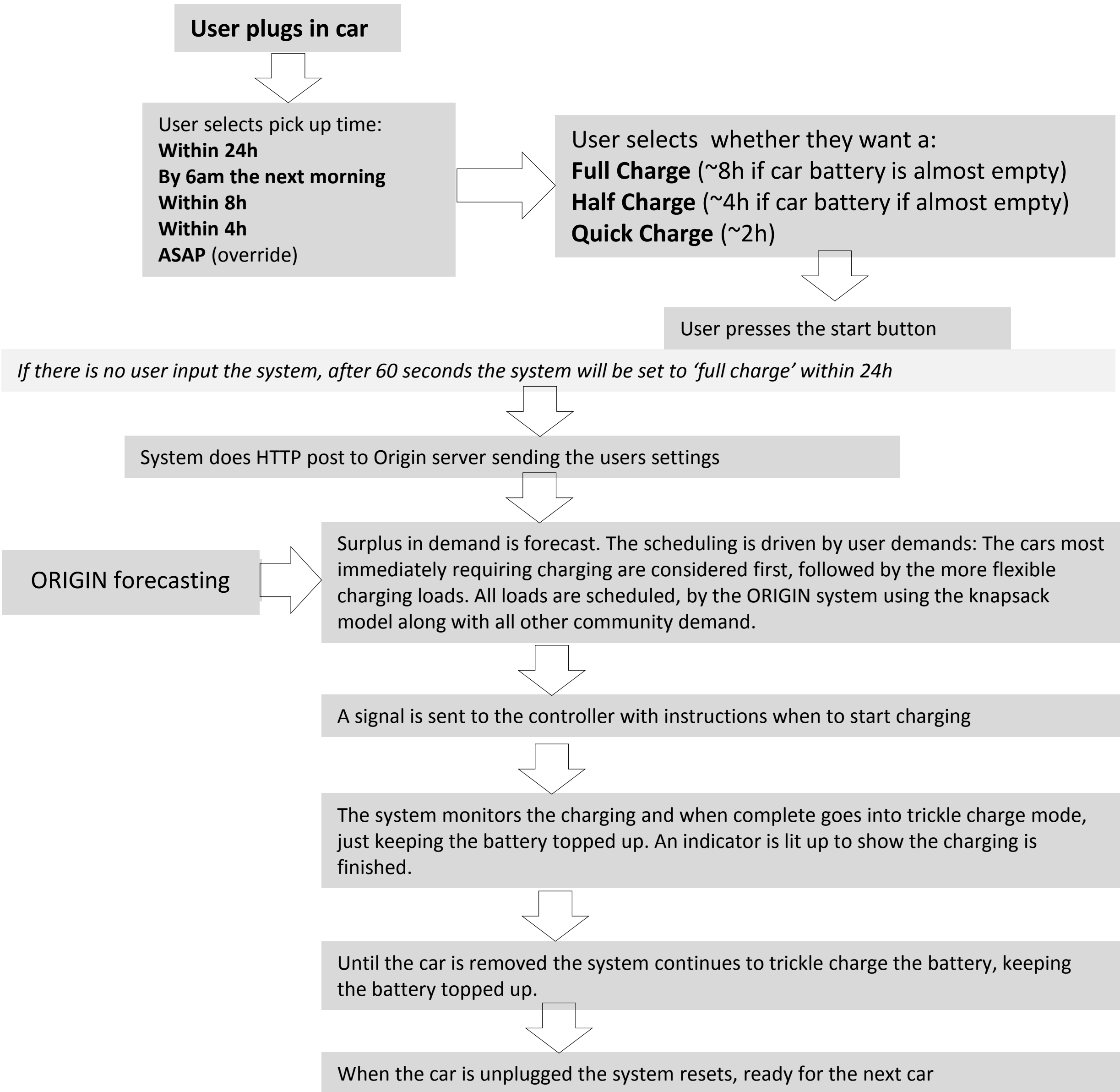


Figure 2: Community defined operating logic for a demand response EV charging system

Market

The necessity of the transition from internal combustion engine to electric, hydrogen or hybrid platforms is well documented with the number of global vehicle sales forecasted to reach 5M pa by 2020 creating a stock of over 20M vehicles[6]. ORIGIN based control that provides electricity network services through scheduling home charging systems to match forecasted output from wind generation can be envisaged. Additionally, ORIGIN systems that match a basket of renewable technologies may be applicable for fleet operators who are operating battery swap procedures to maximise vehicle road times. HWU intend to develop this system further via the Blackwood Green Fleet to Green Fleet project described in the Impact, Dissemination and Exploitation section of this report.

2.4 Findhorn Household Electrical demand - Type of response: Informational - Incentivised

Description

A dynamic wind tariff was developed for the Findhorn Community that linked the price of electricity to the availability of surplus generation from the community owned wind-park[7]. It was deployed in a field trial between March and October 2015 involving 38 households. The tariff schedule changed each day based on the forecasted availability of surplus electricity. The dynamic wind tariff was not continually updated but rather changed on a daily basis and then fixed at one point in time. The time at which the tariff would be published was a balance between two competing factors. The participants requested as much forewarning as possible to increase their capacity to amend energy practices. Errors associated with surplus forecasting however tend to increase with forecast horizon so from the perspective of accuracy the tariff would ideally be as close to real time as possible. The compromise reached was that the tariff for the period 00h00 to 23h59 tomorrow would be published today at 17h00 every day.

Many commentators assert that the transition to a low carbon society will only be successful if residential consumers modify their energy practices. There is also an extensive body of evidence that suggests that this modification will only gather pace when environmentally committed practices become normalised in society. This field trial sought to explore one aspect of energy practice modification in a community where this normalisation has already taken place. To some extent then, it could be argued that the results achieved in this pilot trial represent a *change potential* for incentivised tariff schemes of this nature.

Impact

- 47% of households were active at some point during the six month monitoring period with 21 % active throughout.
- The average scale of response engendered by the change in tariff was found to be 0.11kWh/h for dwellings that were constantly active.

[6] IEA (2013), https://www.iea.org/publications/globalevoutlook_2013.pdf
[7] A more detailed description is provided in D7.7.

- Significant variation was found in the scale of demand response over a 24 hour period with participants non-responsive during the night time as might be expected. Periods of non-negotiable energy consumption also occurred at breakfast time.
- The estimated demand response incentivised by the change in tariff from all 38 participating dwellings during the field trial was found to be 360kWh
- Of this shifted consumption, 248kWh (69%) was coincident with surplus wind generation and therefore resulted in increased in consumption of local generation. The discrepancy occurred because of forecasting errors.
- If the effect of the dynamic tariff were applied to the entire community with the same level of response the increase in local consumption would be 6.29MWh pa. This is equivalent to 0.5% of total generation, or a 1% increase in consumption of local wind generation.
- The *change potential* of the dynamic wind tariff was estimated by applying the demand response achieved by those participants who were active throughout the field trial to the entire Findhorn community. This suggests a potential demand response of 55.7MWh pa, increasing local consumption by 38.4MWh (2.9% of annual generation or a 5.8% increase in consumption of local generation).
- If the scale of response shown here by the continuously active participants, coupled with the inaccuracies associated with its deployment was mirrored on a national scale, the impact on buffering output from wind generation is likely to be marginal at best. For instance, if the entire population of Scotland were to respond akin to the continuously active dwellings in Findhorn, they would be able to buffer 81% of the output from the Whitelee wind farm when its capacity factor exceeded 28%. Whitelee Wind Farm, the second largest onshore facility in Europe has a capacity of 539MW, accounting for 4% of total UK wind capacity in 2014.

Product/service description

The ORIGIN forecasting architecture can deliver estimates of high renewable generation availability at a local, regional or national level up to 72 hours ahead. These could be used by retailers to create dynamic energy tariffs.

Market

Dynamic tariffs have been trialled in a number of FP7 projects and in a more extensive project in London (see D5.5 for more details) with the latter of these trials delivering positive results. Electricity market reform and smart meter roll out programmes are changing the way in which energy will be retailed to customers. This in turn is creating opportunities for new market entrants who are offering distinct products compared to traditional retailing approaches. A market place may therefore appear for dynamic tariffs of the type described here. The approach is only likely to make a small contribution towards the transition of low carbon networks. HWU are seeking to develop the ORIGIN demand reponse system in conjuction with a progressive energy retailer in the "Urbanlink" project.

2.5 Findhorn Household Thermal demand - Type of response: actuated

Description

Sensing and actuating hardware was deployed in 12 dwellings to enable their space heating and domestic hot water (DHW) systems to be directly actuated using the ORIGIN architecture. The potential benefit of directly actuating these systems was modelled over a calendar year; the models being informed by the output from a field trial that was conducted over a shorter time frame (see D5.6 for more detail). Two different, thermally efficient dwelling types were used in the study. The first dwelling type ('Centini') had an energy system comprising an electric boiler feeding a 500 litre storage tank which is also fed by a solar thermal system with a 1.5m^2 roof mounted panel. The maximum amount of energy that can be stored to meet dwelling demand is 20kWh. The second dwelling type ('Whins') energy system has a 200 litre tank serving hot water demand only with a 7kWh storage capacity. There are 14 and 24 'Centini' and 'Whins' dwellings respectively in the Findhorn community.

The modelling assumes that the daily demands must be met i.e. the required energy must be delivered within the 24 hour period and comfort temperatures maintained. Within these constraints, and those imposed by the capacity of storage and the energy system itself, operation was manipulated to increase coincidence with surplus wind generation availability. Two scenarios were considered. The first assumed that the ORIGIN control strategy was applied to energy systems in all 38 candidate dwellings; the second, more theoretical, assumed that the systems controlled in this manner could be applied to all dwellings in Findhorn. This second scenario can therefore be considered as the *technical potential* of this approach.

Impact

The average heating and hot water daily demands were measured as 14kWh and 17kWh for the 'Centini' and 'Whins' respectively in February, and 3kWh for each type in June. This gave a total shiftable daily energy load for all the dwellings of 600kWh in February and 120kWh in June. The heating load during store charging was 4.2kW and 3kW respectively thus providing a cumulative shiftable opportunity of 130kW for all 38 dwellings.

- Scenario 1 was found to increase utilisation of electricity generated by the wind park by 81MWh pa (6%); this resulted in a reduction in community CO_2 emissions of 30.1TCO_2 pa[8] (table 4)
- Scenario 2 was found to increase utilisation of electricity generated by the wind park by 144MWh pa (11%); this resulted in a reduction in community CO_2 emissions of 53.2TCO_2 pa[8] (table 4)

Parameter	Base	Scenario 1	Scenario 2
Cost of energy (pence/kWh)	7.6	7.5	7.5
Total generation from wind park pa (MWh)	1139	1139	1139
Local consumption pa (MWh)	598	679	742
Local consumption (%)	53	59	64

Grid import pa (MWh)	519	454	404
CO_2 emissions (TCO_2)[8]	239.9	209.8	186.7

Table 4: Impact of the thermal model actuation methodology in Findhorn

Product/service description

The end to end ORIGIN architecture utilised to deliver this actuated performance.

Market

The transition to a low carbon economy necessitates changes in provision of space heating and transport and this will have dramatic impacts on the demand for electricity. For instance, in the UK moving from gas to electricity as the primary fuel for delivering space heating in buildings may result in an increase in peak demand of 40GW[9]. This growth coupled with the rise in intermittent generation make the need for active, electrical space heating systems a priority. Whilst this transition is only likely to gather pace after 2020, existing markets are available in Northern Europe for space heating systems that are predominantly electricity based, e.g. Sweden and Norway.

2.6 Findhorn Electrical demand of washing machines - Type of response: informational incentivised

Introduction

The efficiency of informational, residential demand response initiatives has been questioned for two principal reasons; firstly that changing people's energy practices is difficult and secondly there are limited opportunities for load shifting in a domestic environment, particularly if the dwelling does not have some form of mechanical cooling system. The appliance that is most often cited as being shiftable is the washing machine, although the efficacy of this assumption is a matter of debate.[10] This contention made it interesting to investigate the extent to which the timing of use can be shifted based on ORIGIN informational signals.

The dataset used to investigate the load shift opportunity presented by washing machine operation came from 14 Findhorn households. The analyses effectively forms a subset of the wind tariff experiment as each of the 14 dwellings participated in that field trial. In each, washing machine operation was measured using a dedicated voltage clamp at 5 minute temporal precision. The dataset was analysed to quantify the number of washing machine cycles that took place during periods of surplus wind generation from the wind park. The aim of the ORIGIN architecture was to increase this level of coincidence. The extent to which this occurred was determined by creating a dataset for the benchmark period May to October 2014, i.e. prior to the ORIGIN system being

[8] Calculated using the UK grid emission factor for network electricity in 2015 of 0.4622kgCO_2e/kWh and assumes no CO_2 emission attributable to electricity produced by the wind park (DEFRA, 2015)
[9] Eyre, N. and Baruah, P. (2014) Uncertainties in Energy Demand in Residential Heating, UK Energy Research Centre Working Paper
[10] Shove, E. (2003). Comfort, cleanliness and convenience: The social organization of normality (Vol. 810). Oxford: Berg.

deployed in the community. This was then compared to a dataset from the period March to August 2015. The predominant variable affecting whether coincident cycles occurred or not was found to be wind generation. Coincidence was determined by quantifying the extent to which the ORIGIN architecture altered this relationship.

Impact

A linear relationship was found between the monthly capacity factor of the wind park and the proportion of washing machine cycles carried out that month that was coincident with a surplus being available (Figure 3). The effect of the ORIGIN architecture was to increase the number of coincident cycles with for instance the proportion of coincident washing machine cycles increased from circa 25% to 40% when the capacity factor was 20%.

Product/service description

The forecasting element of the ORIGIN architecture was required for the approach described here which relied on the participant as actuator. Participation is likely to be increased by coupling this approach with some form of feedback for which the UI would be appropriate.

Actuated systems could be packaged where ORIGIN software is incorporated within original equipment for appliance manufacturers. A market of this nature is only likely to be stimulated by EU appliance legislation. Alternatively, a market for after sales products may emerge which facilitates the load shifting of washing machines (and other appropriate appliances) of systems through smart plugs with associated communication technology.

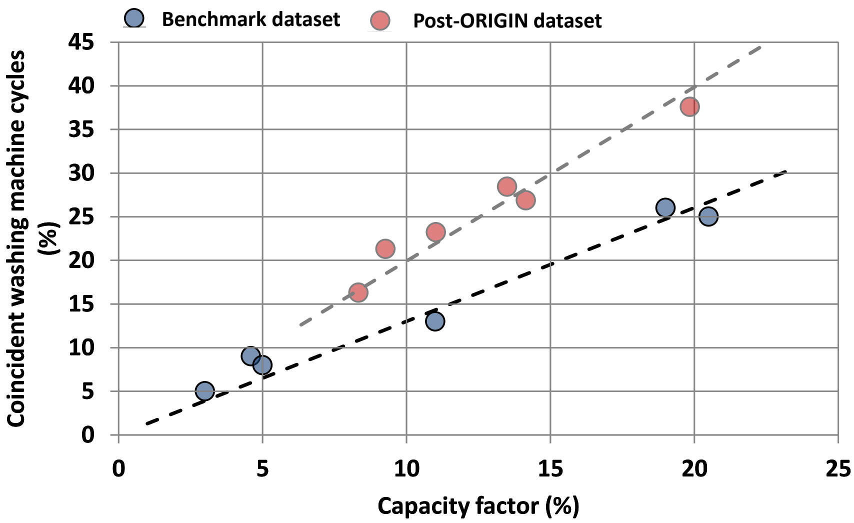


Figure 3: Effect of capacity factor on the number of washing machine cycles coincident with surplus wind generation from the Findhorn wind park

Market

Using a series of assumptions[11], it is possible to determine the impact of this change if this level of demand response were to be repeated at a national scale using the UK as an example. If similar changes in energy practice were observed then the ORIGIN system would result in the additional consumption of 606GWh of wind generation, equivalent to 2.8% of total UK wind output at 20% capacity factor and the amount of installed capacity seen in 2015 (Table 5). Clearly, the impact would be substantially magnified when applied to the EU which has over eight times as many households as the UK and where ownership of washing machines is either at or nearing saturation levels.

Parameter	Quantity	
Energy consumption of a washing machine	117	kWh pa
Number of additional coincident cycles delivered by ORIGIN system	1	out of 5
Energy that is now coincident with wind	23	kWh pa
Number of households in the UK	27.6	M
Washing machine ownership	97	%
Total energy consumption of washing machines	3,030	GWh
Additional energy consumption that is coincident	606	GWh
Wind capacity of the UK	12.43	GW
Capacity factor	20	%
Wind output of the UK	21,777	GWh
Additional wind generation consumed by washing machine operation	2.8	%

Table 5: Impact if change in energy practice with respect to washing machine operation at Findhorn was translated to the UK

2.7 Findhorn Community electrical demand - Type of response: informational

Description

A dataset was compiled that contained the total electricity demand for the Findhorn Community and the wind generation from the wind park at a temporal precision of five minutes for the period 9th March to 30th September, i.e. after the ORIGIN system had been deployed.

The total number of buildings in Findhorn is approximately 120 with 61 directly participating in the ORIGIN project in that they have had monitoring/actuating equipment installed. Of these participating buildings, the 38 which were directly involved in the dynamic wind tariff field trial were responsible for circa 10% of total community demand. The analysis presented here investigated the extent to which the community as a whole responded to the information provided by the ORIGIN UI. Occupants of the 61 participating buildings had unique log in details and were able to access energy data pertaining to their specific building in addition to the forecasted availability of surplus

[11] Washing machine ownership in the UK is 97% (ONS, 2015); the average number of washing machine cycles per annum is 255 (Jenkins et al., 2012); the average energy consumption of a washing machine where the maximum cycle temperature is 60°C and the sud volume is 10 litres is 117kWh pa (Jenkins et al., 2012)

electricity generated by the wind park. Other residents were however able to engage in the project as a screen relaying the forecasts and community level energy data was installed in a prominent place in the community centre.

The aim of the analysis was to quantify the extent to which the energy practices of the Findhorn Community changed in order to increase the proportion of electricity generated by the wind park consumed locally. In order to quantify any impact it was necessary to establish the proportion of wind generation that was used by the local community prior to the ORIGIN system being installed, i.e. their benchmark energy practice. The method by which this was carried out is described in section 3.3.1 in D5.5, and resulted in equation (1). This equation was applied to the post-ORIGIN dataset and compared to the observed E_{used} data (Figure X).

$$E_{USED} = 105 - 0.767D_L - 0.125E_{MAX} + 0.0373E_{DEM} \quad (1)$$

E_{USED} Proportion of electricity generation from the local wind farm used by the community (%)

D_L Day length (hours of daylight)

E_{MAX} Maximum hourly electricity generation per day (kWh)

E_{DEM} Daily community electricity demand (kWh)

Impact

- The total electricity generated by the wind park during the period covering the post-ORIGIN dataset was 384.6MWh
- The pre-ORIGIN energy practice described by equation (1) would have utilised 201.0MWh (52.2%) of this generation locally
- The actual amount that was used was 210.4MWh (54.7%), an increase of 9.4MWh (2.5%)
- This resulted in CO_2e savings of 4.34TCO_2 broadly equivalent to the total annual CO_2e emissions attributable to an average UK dwelling.
- Response fatigue is clearly evident from the community response with little difference between the benchmark and observed level of local consumption observed after mid-June (Figure 4)

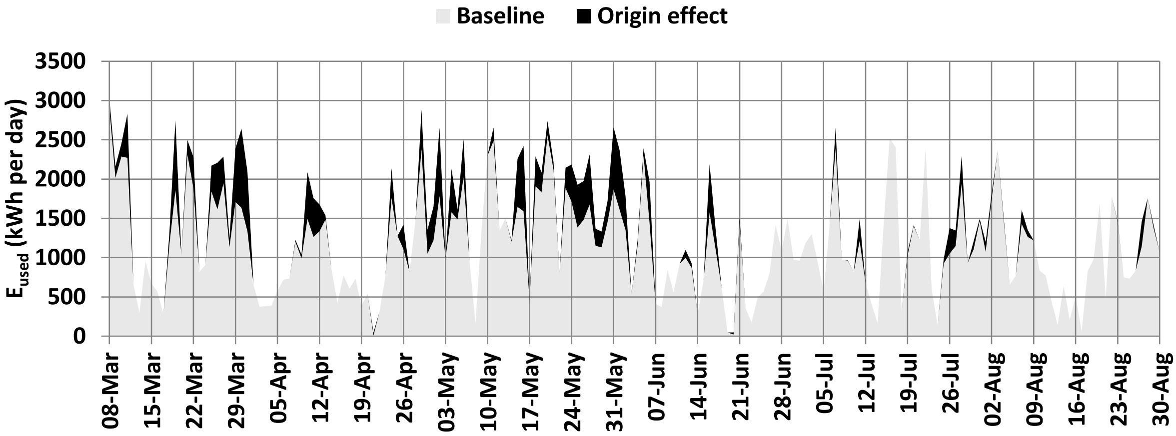


Figure 4: Additional locally generated electricity used in the Findhorn Community that is attributable to the ORIGIN system

Product/service description

The ORIGIN forecasting algorithms were able to deliver this demand response project coupled with a communication method for which the ORIGIN UI would be appropriate.

Market

The Increased urbanisation is placing a greater emphasis on the Smart Cities agenda to deliver technologies and practices that will contribute towards the low carbon transition. The European Innovation Partnership on Smart Cities and Communities (EIP-SCC) currently has 370 projects with 4,000 partners in 31 countries in Europe. The scale of the transition town movement also provide some degree of the market size that might be available to community led, demand response initiatives, It is estimated that by 2011 there were over 400 registered transition towns in 34 different countries[12]. With respect to intentional communities similar in nature to the three pilot sites included in the ORIGIN project, the Global Ecovillage Network database listed more than 30 communities of more than 100 residents in Europe[13]. These are likely to be sub-sets of the 15,000 micro-grid systems described earlier.

[12] Fudge, S., Peters, M., Hoffman, S. M., & Wehrmeyer, W. (Eds.). (2013). The Global Challenge of Encouraging Sustainable Living: Opportunities, Barriers, Policy and Practice. Edward Elgar Publishing.
[13] http://db.ecovillage.org/en accessed November 2015

3. Summary energy and carbon savings

In conclusion it can be stated that the demand response potential of communities and neighbourhoods is highly variable and depends upon energy resources of the community in question. (Table 6).

The Damanhur community demonstrated an average demand response equivalent to an increase of 3% in self-consumption of community generation and an annual savings of 374 kgCO_2e per annum at the Magilla building.

The highest potential to increase the utilisation of community generation found during ORIGIN was at the Tamera community. This was specifically due to the high degree of PV curtailment on site, because of control issues with their energy network, particularly with respect to charge and discharge cycles of batteries. The introduction of electric vehicle charging infrastructure coupled with an ORIGIN informed charging control strategy for both vehicles and on site battery storage has the potential to increase utilisation of community generation by up to 32% saving 6.6 TCO_2e per annum.

The Findhorn Community have by far the most complicated energy infrastructure amongst the Validation Communities. In addition their lifestyle is probably closest to the general population in that they live in relatively standard family residential units. The results from Findhorn probably represent the most likely outcome for general deployment of ORIGIN demand response. In addition to informational feedback and actuated demand response programmes an incentivised program was also trialled in Findhorn for some of the community residents. The results demonstrated that incentivised demand response coupled with actuation of electrical space heating and hot water loads would result in a 16.8% increase in the use of local generation and a corresponding reduction of over 37 TCO_2e per annum. At the same time the non-incentivised response coupled to actuation was found to increase utilisation by 13.5% and reduce emissions by circa 30 TCO_2e per annum.

Demand response project	**Type of response**	**Percentage increase in use of Community Renewables**	**GHG Emissions Savings / kgCO_2e per annum**
1. Building electricity demand (Damanhur)	Informational – feedback (Measured)	3%	374
Total Demand Response (Damanhur)		3%	374
2. Improved micro-grid control (Tamera)	Quasi-actuated (Modelled)	22%	5,400
3. Electric Vehicle Charging (Tamera)	Actuated (Modelled)	10%	1,250
Total Potential Demand Response (Tamera)		32%	6,650
4. Household electrical demand (Findhorn)	Informational – incentivised (Measured)	5.8%	12,900
5. Household thermal demand (Findhorn)	Actuated (Modelled)	11%	24,400
7. Community electrical demand (Findhorn)	Informational - with feedback (Measured)	2.5%	5,500
TOTAL Response without tariff incentives (Findhorn)		13.5%	29,900
Total Response with tariff incentive (Findhorn)		16.8%	37,300

Table 6 Summary of demand response potential at each of the communities from different project scenarios.