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Orchestration of Renewable Integrated Generation
in Neighbourhoods – Grant agreement number 314742

ORIGIN Final Report

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Executive Summary

The ORIGIN project demonstrated applied and modelled demand side management of energy use in three validation communities in Scotland (Findhorn), Portugal (Tamera) and Italy (Damanhur). The communities were selected based on their prior investment in renewable energy generation systems and commitment to a sustainable approach to energy resources.

The project deployed an end to end operation of a new breed of energy control architecture to facilitate demand response in a bespoke form in each of the validation communities. The starting point for the system is a new technology for accurate localised weather (and renewable generation) forecasting. It utilises new software technology for achieving demand-response from community-level energy actions. In order to enable the residents of the communities to participate in active demand response the project developed a web-based graphical and numerical user interface using a participatory design approach to involve the communities in the design process. The user interface was customisable to the needs of the individual participants to ensure effective communication of demand response actions, historical and current energy usage and energy pricing signals.

During the project the consortium executed three different demand response models in the validation communities and modelled the potential of three others. The biggest potential positive impact upon increasing uptake of community generated electricity was shown to occur where community generation is curtailed by an inability to export to a national grid infrastructure. This was the situation in the validation community in Portugal where the research concludes that demand response and associated energy management could result in an increase of 33% in the uptake of photovoltaic generation.

In the wind generation dominated community in Scotland a maximum demand response of up to a 16% increase in uptake of renewable generation was estimated via a combination of an incentivised participatory demand response system, driven by price signals and energy information supplied via the user interface, and the modelled impact of automated actuation of thermal space and water heating.

In the Italian validation community the ORIGIN demand management system achieved a 3% increase in the community's use of their own roof-mounted photovoltaic electricity through active participatory involvement in demand response actions via the user interface.

ORIGIN highlighted that, even with the encouragement of financial incentives, there is a need for repeated engagement with the end users to relate the ongoing impact of consumers' their participation in the demand response management of their energy lifestyles.

The project results suggest that a viable business case can be made for a forecast informed actuated community scale demand response initiative if the community can trade with the local DNO. Although current revenue streams are small, new energy markets are emerging in response to the transition to a low carbon economy and this is likely to create additional revenue opportunities in the coming years.

The project has produced, or is producing: 20+ academic publications; a joint venture agreement between seven of the consortium members; one spin out company to date; ten innovations; at least one patent application; a series of new product developments; and 11 applications for further funding from various potential sources, two of which have been funded at the time of writing.

PROJECT CONTEXT AND OBJECTIVES

1. Context

In the European Union (EU) energy usage in buildings is responsible for approximately 40% of the total energy consumed each year by the member states and 36% of total EU CO_2 emissions. Improved efficiency could therefore have a major impact. ORIGIN focuses on three specific foundations that provide opportunities for improving this efficiency:

1) Increasingly many communities across the EU have installed a variety of renewable energy systems.
2) The potential of renewable generation to achieve carbon emission savings is severely restricted by the fact that renewable supply is often poorly aligned with energy demand.
3) At the community or neighbourhood level, significant additional opportunities exist for optimizing the alignment of renewables supply with community demand.

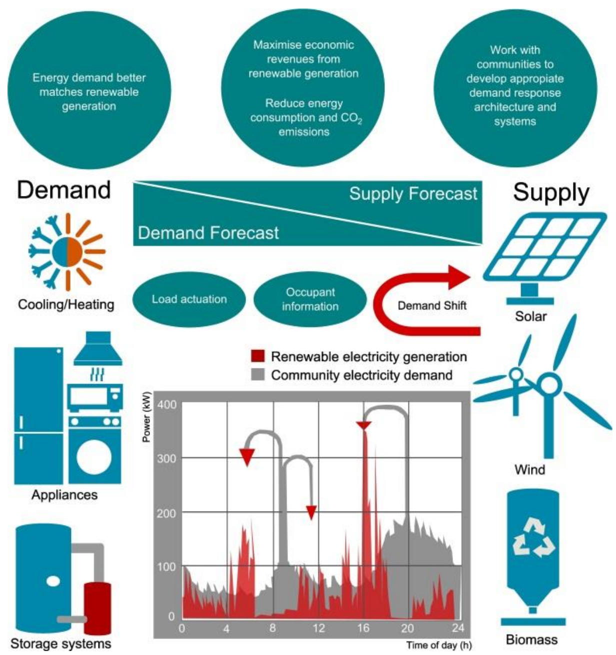

Fig 1 Typical Community electricity demand and renewable electricity generation

Recognising these opportunities, the elements of ORIGIN's approach were as follows:

- Advanced mathematical forecasting techniques were used to continually forecast renewables supply and energy demand, at both individual building and community levels, and for various future time windows;
- An energy and environmental monitoring infrastructure was installed in each of the three validation communities to inform the forecasting mentioned above.
- A participatory demand response system was installed to enable the communities to make well informed personal decisions regarding the timing of their energy use to seek alignment between supply of community generated renewable electricity and local demand.

ORIGIN has 8 beneficiaries: Heriot Watt University (HWU), Virtual Power Solutions (VPS), University of Strathclyde (UoS), Insituto Tecnologico de Informatica (ITI), Fraunhofer Gesellschaft Institute for Solar Energy Systems (FISE), Findhorn Foundation College (FF), ILOS (TAM) and Solera SV (DAM). Heriot Watt University is the project coordinator with the UoS, FISE and ITI acting as academic partners. The key role of VPS has been to provide monitoring and actuation hardware and the associated software customised to the project's needs.

The three validation communities (FF, TAM and DAM) were chosen for their disparate climates and energy use characteristics and for their renewable generation capabilities. The communities are all established intentional eco-communities, but they each operate with distinct attitudes, lifestyles and philosophies that differentiate them from each other. The communities contain different mixtures of building styles and uses which enabled the consortium to demonstrate the adaptability and transferability of the technology.

The Findhorn Foundation Community is located in the North East of Scotland approximately 50km from Inverness. There are a variety of building types including, offices, restaurant, concert hall, arts centre, shop, launderette and circa 130 dwellings of varying construction type, age and energy efficiency. The renewable generation mix includes a 675kW wind park, 15kW of roof mounted solar PV, solar water heating systems and biomass heating systems. Space heating is delivered to each of the buildings using a mix of individual building and district heating systems.

Tamera is a community of approximately 120 people located in Southern Portugal approximately 190km south of Lisbon and 30km inland from the coast. The community comprises a number of residential and community buildings, e.g. communal cooking and eating area, assembly hall, bar and conference areas. The community operates a grid connected island power network. There are a number of PV systems which at the start of the project totaled 20kWp, but was increased to 32kWp during the project.

The Damanhur Community is located in the North-West of Italy approximately 30km from Turin. Whereas the other two communities can be defined wholly by a geographical space within which all buildings and occupants are community members, Damanhur buildings and community members are spread over a geographical area of more than 30km^2, with buildings being located within mainstream settlements. Many of their buildings include PV systems including a 120 kW array housed at their Crea site (which houses a shop, café and office space), and a building integrated 27kW system at the Magilla 'nucleo'.

2. ORIGIN Objectives

The primary objective was to demonstrate significantly increased carbon emissions reductions in large and small groups of buildings, via the use of the ORIGIN smart ICT architecture. The following is a list of a series of subsidiary and associated objectives in the order in which the consortium expected to meet them during the project.

O1: The first objective was to develop the ORIGIN smart ICT architecture and deploy it in each of the three validation communities (Damanhur, Findhorn, Tamera). The ORIGIN smart ICT architecture represents the full integration of the prediction algorithms, control algorithms, optimization algorithms, their interfacing with energy network components, smart meters, and associated communication protocols. This major objective refers specifically to deployment of the system in the three communities.

O2: The second objective was to evaluate and demonstrate the acceptability to users of the ORIGIN approach, i.e. to demonstrate the "livability" of the technology. This was to be achieved by gauging the attitudes of the end users in the three validation communities. The system was designed to be as user friendly as possible and to minimise disruption to the lives of the occupants of the buildings. However the participation of the end users was essential to the successful completion of the project and the consortium developed a bespoke ORIGIN user interface to enable clear and convenient energy information to be presented to the participants. Feedback from the communities was gathered through this online user interface; however the consortium also ran a series of community engagement events in each of the communities to inform the participants of progress and updates. The user interface was designed using participatory design concepts involving the residents of the communities.

O3: The third objective was the delivery of community energy development plans, and associated methodology; we intended to advise each community on the most appropriate further opportunities for development in their portfolio of energy infrastructure. This task identified significant opportunities to increase uptake of community generated renewable energy and led to clear advice on future energy system investment for the communities.

O4: The fourth objective was to demonstrate significant imported energy savings in each of the validation communities by increasing the uptake of community generated electricity. The project validation phase intended to compare the community energy use characteristics before and after deployment of the ORIGIN algorithm. Sensors and monitoring equipment were installed before the control algorithm was finalised and deployed in the energy monitoring and control system. This enabled the consortium to gather energy generation and use data prior to the initiation of the system. During this period the system operated simply as a data gathering tool to provide the information required for future validation. Information was provided by the three communities about their estimated energy demand and production prior to the start of the project. The methodology used to calculate energy and carbon savings was determined in WP4, building on emerging standards from other EU projects and most appropriate best practice for these communities. Following ORIGIN deployment, a before and after comparison began and continued until the end of the project and beyond. The quantified and complete evaluation was documented in deliverable D5.7.

O5: The fifth objective was to define and deliver a transferable implementation process and associated resources. This was intended to enable the system to be installed in other "communities" and enable it to be further exploited by the consortium following the project. The process followed in ORIGIN was refined and documented to enable replication. It was created with the intention of enabling the integration of numerous energy products from different vendors and property developers, renewable energy technology suppliers and other interested parties, to encourage the opening of new markets. D5.8 and D8.3 documented this process further.

O6: The project also intended to define a range of appropriate business models for energy-aware communities. These business models would consider three main issues. First, the internal dynamics and tariff options within such communities, which will typically include many small and medium-sized potential suppliers of energy. Second, options and issues for ensuring that such a community can meet its own defined goals (such as achieving a specific balance between cost savings and CO_2 savings), while ensuring fair competition and prioritisation within the community. Thirdly, business models would be explored in relation to the community's interface with the national electricity supply. In each case, recommendations would be made to the communities. The associated documents were produced in Deliverables D7.2 and D7.3.

O7: The final objective of ORIGIN was to achieve widespread dissemination of project results. The dissemination phase was designed to publicise the results of the project to a variety of audiences. The objective was to maximise the exposure of the results to targeted audiences including the public, media, academia and potential end users. These activities are described in the Innovation, Dissemination and Impact section of this report and in deliverables related to work package eight.

3. Knowledge Enhancement

Previous projects and studies have focused on the management of energy in selected individual buildings . The system implemented in ORIGIN addresses the mismatch between energy supply and energy demand by integrating consumption and generation subsystems on a neighbourhood or community scale.

In brief, ORIGIN's intended advances beyond the state of the art can be summarised as the following list of distinct elements, while a key advance in itself is the integration of all these elements within a single solution:

3.1 Prediction of energy demand at building and community levels.

ORIGIN set out to develop techniques to predict energy load in individual buildings and aggregate this into community energy demand prediction. Aggregate demand would be forecast in each of the communities to enable the identification of locally generated renewable energy surplus of sufficient magnitude and duration to enable effective demand response increase in the uptake of renewable generation.

3.2 Prediction of community renewables supply.

The project team would create a novel and highly accurate method of predicting weather conditions in each of the communities. This highly accurate weather forecast would then be used to predict renewable generation at each site. This renewables forecast would in turn be combined with the energy demand forecast to identify future period of surplus renewable generation.

3.3 Optimisation to deliver control actions and suggestions

ORIGIN would optimize demand response in the communities allowing for: (i) detailed predictions of demand and of renewable supply; (ii) the particular goals of the community with respect to energy, emissions and cost.

3.4 Hierarchical coordination structure

ORIGIN would develop a new hierarchical co-ordination architecture that could become an exemplar for community-level energy management and control systems. It would take account of community goals and ideals as well as the available periods of demand response and crucially it would prioritise energy supply to minimise carbon emissions. For example local wind or PV generation would be prioritised over dispatchable sources such as wood pellets and heat pumps. A community level approach would take into account community, social, environmental and economic goals.

3.5 Informing and empowering residents to make energy decisions

ORIGIN intended to empower residents and occupants with clear and rich information about current energy usage, predicted demand, and predicted availability of renewable generation, along with justified suggestions for behavior and control actions. The project would strive to advance the state of the art in delivering actionable information based on forecast renewable energy surpluses.

4. Summary

The availability of renewable generation is often non-coincident with the demand for energy within buildings. Maximal use should be made of renewable supply when it is available, and excess should ideally be stored or utilised for elements of demand that can be rescheduled into surplus windows. ORIGIN would enable people in communities, or individual buildings to make informed energy decisions that met the overarching goal of increasing the uptake of local renewable energy generation and thus reducing the import of non-renewable generation from the grid infrastructure. The optimization process would be developed to take into account the energy demands of the individual buildings, the energy goals of the communities and exploit energy storage opportunities to achieve demand response at a community scale.

MAIN SCIENTIFIC AND TECHNOLOGICAL RESULTS

1. End to End Demand Response System

1.1 Achievement Highlight: Deployed End-to-end operation of a new breed of Energy Control Architecture

The high-level ORIGIN control architecture was designed to help energy-aware communities improve their energy management. In particular, the focus was on helping communities that are already 'energy conscious' (having community-owned local renewables) to enhance the utilisation of their renewable energy sources. This was directly in response to the challenge of integrating these renewables, expressed in call FP7-2012-NMP-ENV-ENERGY-ICT-EeB, area EEB-ICT-2011.6.5 *Energy-positive neighbourhoods*.

We designed and built this architecture, and installed and deployed it in three communities, achieving sustained 24/7 end-to-end operation in each community. In the process, many significant socio-technical challenges were faced and overcome, and many technical advances were made. One indicator of the overall success of the architecture is that each of the three communities wish the end-to-end operation to continue, and the consortium has agreed to continue supporting its operation for at least 12 months following the end of the project.

To help convey the broad nature of this achievement, Figure 1.1 recalls the high-level energy control architecture as shown in our 'Replication Pack' (Deliverable 8.3), amended to highlight the core-level 'end-to-end' operation via the graphic at the right hand side.

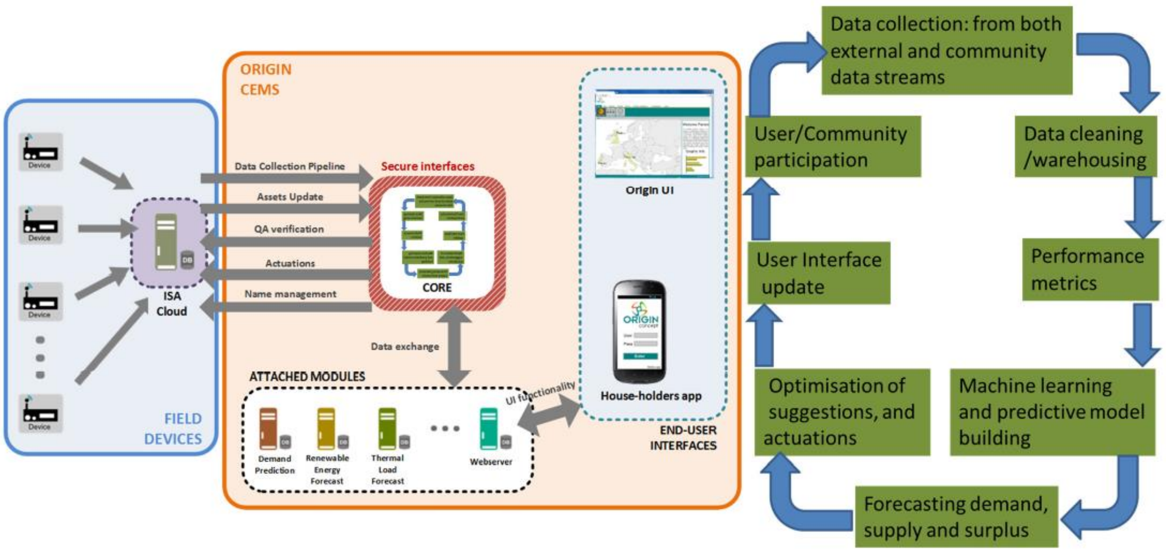

Figure 1.1: Characterising end-to-end operation (right) of the ORIGIN control architecture (left)

Referring to the right-hand-side of Fig 1.1, first, data collection builds on earlier achievements of community auditing (Deliverable 1.1), hardware procurement and installation (Deliverables 3.1, 3.2, 3.3), all linked intimately with community engagement, in parallel with the design and setup of a software network infrastructure to collect all data from ORIGIN-installed sensors. The data collection step itself comprises the following fully automated activity every hour: (1) using APIs and bespoke software to harvest approximately 200,000 distinct items of data related to weather in the region of the ORIGIN sites (2) collection of data from approximately 1100 devices (largely current clamps, heat meters and temperature sensors) from hardware installed in the communities. The second step, 'Data cleaning/warehousing', then harnesses several bespoke software systems to validate and (where necessary) clean all of the data, and install it into the ORIGIN Database (ODB); the full data schema for the ODB is available at [ODBS], and has evolved to contain 50 interlinked tables, smoothly integrating the regularly collected and time stamped raw data with the outcomes of multiple calculations and transformations based upon it. The latter includes the performance metrics, which drive the gadgets on a web based User Interface, themselves based in part on the outcome of machine learning and predictive modelling, to predict demand and renewables supply in each community, altogether involving the running of, on average, 150 machine learning model runs per hour, with approximately 600 individual forecasts made per hour. The optimisation stage then handles around 200 'opportunities' per household, and derives an ideal set of control suggestions/actions, which are then delivered to the ODB and either picked up by the User Interface or actuated via VPS's Cloogy smart plug or similar devices. User participation then completes the cycle and sets the scene for the next stage; all residents in each of the ORIGIN communities participate to different extents, by shifting or otherwise altering their energy demand, and this behaviour becomes part of the data collected as the cycle begins again.

The entire end-to-end system has been operating relatively trouble-free[1] since 5th November 2014 to date (starting at Findhorn, and in all three communities from 3rd December 2014), with additional features (such as the dynamic wind tariff -- see Deliverable 7.7) incorporated from spring 2015. In addition to benefits to the communities and the rich experience of lessons learned the project has generated datasets for continued research (Deliverable 5.7 and elsewhere), this has led to much media

[1] occasional downtime caused by power supply failure, after which the ORIGIN system rebooted successfully each time

interest and interest from a number of other communities and organizations who wish to replicate or adopt similar systems, as evidenced in our discussion of ongoing bids and projects (Please refer to the section on Innovation, Dissemination and Impact)

1.2 Achievement Highlight: New software technology for accurate localized short-term weather forecasting

US patent application 14/933211 (pending) was filed on 5th November 2015, concerning technology for accurate localized forecasting of weather variables. This patent emerged entirely from one of the innovative aspects of our approach, being the inclusion of predictive software technologies as a core component, thereby enabling control decisions to be informed by a significantly better picture of renewables availability in the next 1--48 hours.

In our original project proposal, we recognized the idea that accurate predictive technology could be the key for a new type of energy management architecture. The vision was that reliable forecasts would enable end-users to better plan their short-term future demand. For example, if the turbines are currently stationary, but strong winds are predicted for tomorrow afternoon, use of the washing machine can be deferred until then. On the other hand, if it is sunny now but cloud cover is predicted to be high for the next 48 hours, it would be wise to bring forward any movable energy-rich activities that had otherwise been envisaged for the next two days, such as charging EVs or mowing the lawn.
In the early stages of the project itself, as we engaged the communities in the system design process, and started to explore and experiment with current predictive technologies, four further things became clear: (i) 'Mid-short-term' forecasting was particularly important: users preferred to plan for *tomorrow* based on information provided *today* (e.g. in the early evening). Forecasting for 7--31 hours ahead was therefore highlighted as critical; (ii) current software technology for such mid-term localized forecasting was under-explored; relevant related work typically focussed on 1--12 hours ahead; (ii) we noticed the increasing availability of online observation and forecast data via APIs, and the fact that this had yet to be explored in localized weather prediction; (iv) we recognized the large potential market for accurate localized weather forecasting, in terms of energy-management applications, as well as very widely beyond.

Bringing together the above observations, we developed new technology for accurate localized weather forecasting, which is now the aforementioned patent application, known in the ORIGIN context as the 'WPA' (Weather Prediction Algorithm). The WPA is described in Deliverable 4.2, while the details behind some extensions defined (at high level) in Deliverable 4.7 are under consideration for an EU based patent submission. The capability of this new technology is a component of several of the ORIGIN impact and exploitation routes under investigation, such as AWF, AVC, RHC, HPC, DHO and TSO (see the exploitation section of this report for further details). Examples of the capability of the WPA have been described in deliverables 4.2, 4.7, and also [Corne et al, 2014]. The latter demonstrations have focused on prediction of weather variables relevant for renewables prediction. For this report, we provide some additional material to emphasise the wider potential of the WPA. To that end, Fig 1.2 shows the performance of the WPA in predicting air pressure at Damanhur, in comparison with predictions from 'forecast.io' (the most accurate freely available alternative), for a two-week period in October 2015.

The relative performance of the WPA displayed in Fig 1.2 is in line with what we typically find across the range of predictive targets and variables on which the WPA has been tested. A further example is shown in Fig 1.3, which again shows superior performance for the WPA, this time for forecasts of ground-level ozone concentration at Tamera. The relative reduction in the WPA's improvement at 36hrs-ahead, contrasted with 48hrs-ahead, arises from the fact that ozone-level is strongly influenced by the daily temperature cycle, which makes it easier for statistical methods (which the WPA fundamentally is) to forecast discrete numbers of days ahead rather than fractions.

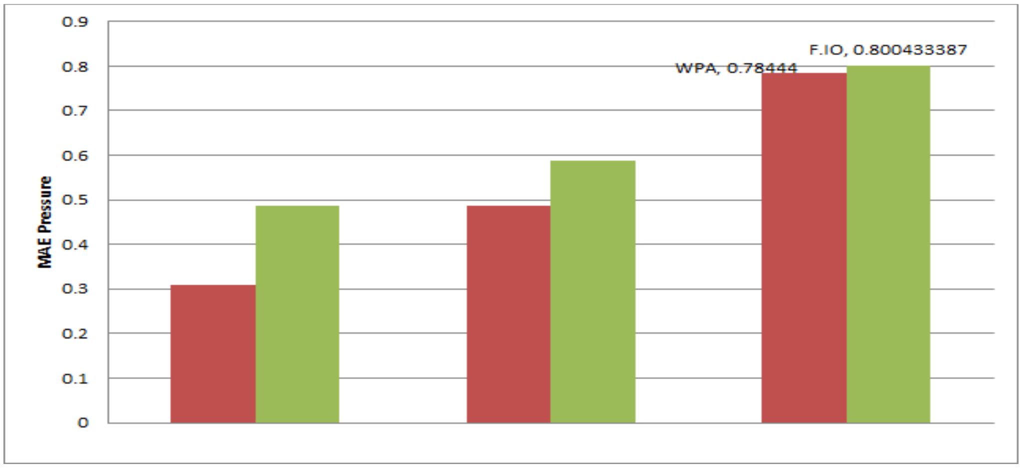

Figure 1.2. Comparing the WPA and forecast.io on air pressure forecasts for Damanhur in October 2015; mean absolute errors for WPA and forecast.io respectively are in red and green, and from left to right the pairs of bars are for 24hrs ahead, 36hrs ahead, and 48hrs ahead forecasts.

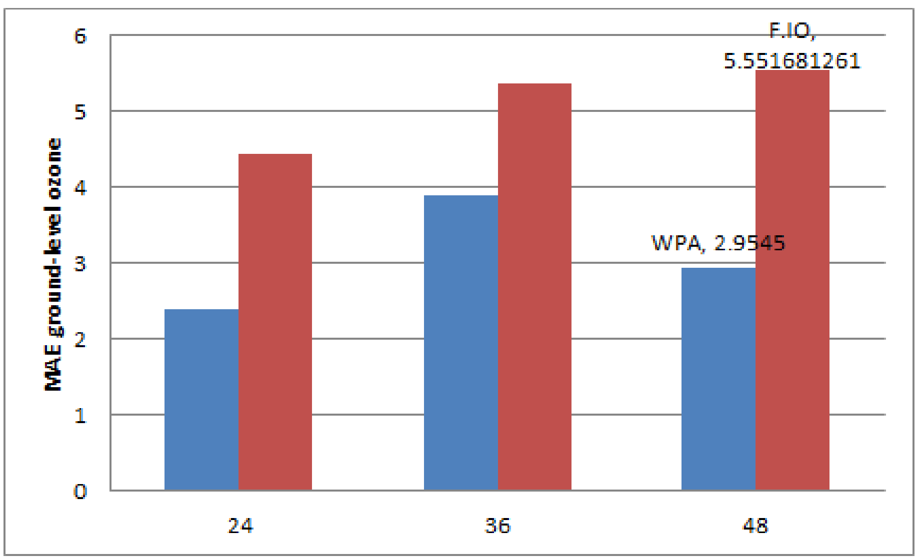

Figure 1.3 Comparing the WPA and forecast.io on ozone-level forecasts for Tamera in October 2015; mean absolute errors for WPA and forecast.io respectively are in blue and red, and from left to right the pairs of bars are for 24hrs ahead, 36hrs ahead, and 48hrs ahead forecasts.

The accuracy of the WPA's forecasts were seen by the communities as a standalone benefit of ORIGIN. That is, in addition to the WPA's value in underpinning the renewables forecasting, the WPA's raw outputs (also displayed at the User Interface), were seen as useful planning aids for general day to day activity. The wider potential of this technology centres around any context where accurate localized weather prediction is valuable; beyond myriad applications in smart grid and renewable energy management this includes planning of outdoor activity, ranging from major construction plans to sporting events. The Innovation, Dissemination and Impact section indicates some of the ongoing activities that are exploiting this capability.

1.3 Achievement 3: New software technology for achieving demand-response from community-level actions

'Demand-response' refers to schemes and systems in the energy market whereby, typically, end-users are incentivized to reduce their demand at peak times [Torriti et al, 2010]. In current practice, the end-users in such schemes are invariably large employers, and/or factories. To the extent that the residential sector is involved in demand-response programmes, this is via entirely automated systems with low take-up, and is currently a negligible part of the demand response scene. However, the importance of demand response is immense. The costs of ensuring grid electricity supply at times of peak demand across the EU are vast, and growing: in the UK this cost is currently approx €1.4Bn per annum, entailing approx. 7M tonnes of CO_2 (equiv. of 1.9M homes). Meanwhile, the EU residential sector, with approx. 214M households, provides (under reasonable assumptions) a daily reservoir of re-schedulable load of potentially 20GW. Currently this reservoir of demand-response is almost completely untapped. However, with this potential realised, the financial and environmental costs of peak-time grid security could either vanish or become drastically reduced in many regions of the EU.

The ORIGIN project has taken one of the first steps towards this goal of tapping into residential demand response, demonstrating that, using the end-to-end architecture discussed above, in the near future it should be possible to tap into residential demand-response at scale. In ORIGIN we engendered this user-participation via two main mechanisms: (i) regularly updated 'green codes' that participants viewed at the user interface via our 'energy clock' (see Deliverable 5.2 (section 3), and Deliverable 8.3 (section 8), and also Innovations TSO, RHC, AVC and SET- see Innovation, Dissemination and Impact section of this report for details); (ii) overall orchestration of end-user suggestions and optimized actuations in selected residences (Deliverable 4.3).

The 'green codes' represent the forecast level of renewables surplus (or deficit), from 1 to 48 hours ahead of the current time. They translate the outcome of renewables and demand forecasting into four colour levels, with dark red representing a clear deficit, and bright green representing a clear surplus, designed to be straightforward for end-users to interpret. They are displayed at the user interface via the energy clock, updated hourly, drive textual suggestions, and essentially characterise the information conveyed hourly to end-users. Figure 1.4 shows the hourly vector of 48 green codes for a typical week at Findhorn.

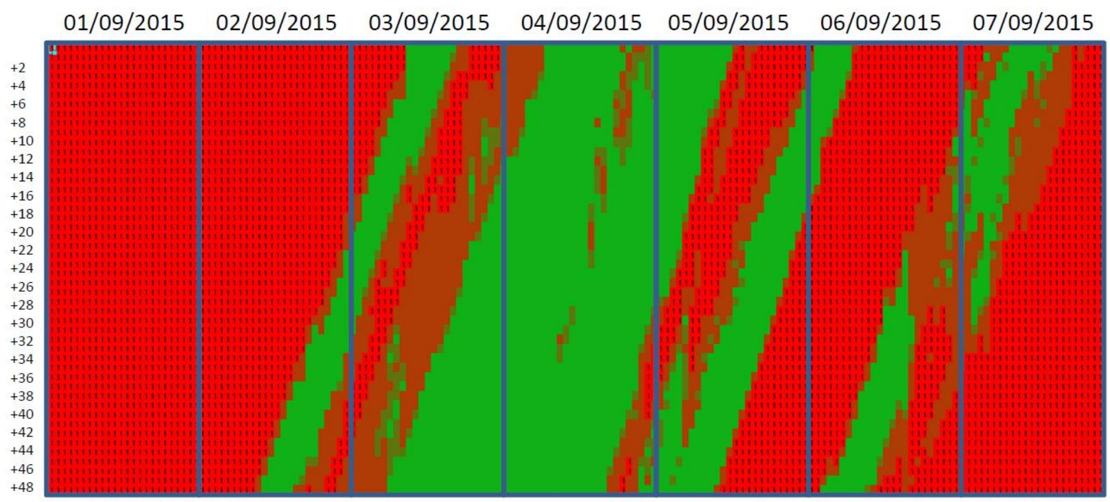

Figure 1.4. Evolution of green code vector from 1st September 2015 to 7th September 2015 at Findhorn; each day includes 24 rows of 48 vertically arranged green codes.

The figure summarises the 8,064 individual green codes (48 per hour) calculated and conveyed via the user interface during a single week, providing every end user with a reliable indication of the levels of surplus renewables expected over the next 48 hours. End users responded in individual and usually positive ways to this information. For example, when the 'wind tariff' was operating (Deliverable 5.5), we were able to show an increase in the degree to which washing machines were used during periods of excess renewable energy availability (and consequently reduced usage during periods of deficit in renewables). This and other analysis of user response appear in Deliverables 5.5, 5.7 and 7.7. Meanwhile, Figure 1.5 shows the automated actuations delivered by the optimisation algorithm for a week in November 2015 for each of three actuated homes in Findhorn. The goal of the optimisation algorithm (as agreed in each community) is to maximise utilisation of renewables, but this means that suggestions and actuations need to be arranged with care when the surplus is forecast to be small, otherwise over-exploitation will lead to over- use of grid energy that could otherwise have been offset by a different period of renewables excess in the near future. Figure 1.5 evidences how the optimisation algorithm orchestrates load-shifting to achieve this balance when the excess is small. For example, in day 1, the actuations are spread out across a 17-hour period, harnessing a moderate level of forecast sustained surplus, while on day 6 they are concentrated into a 6-hour period, exploiting a forecast period of high surplus.

Figure 1.4 (via the green codes' influence on user participation) and Figure 1.5 combine to exemplify the end-user participation that completes the cycle at the right-hand-side of Figure 1.1, translating at scale into the residential demand-response elicited by the ORIGIN energy-management architecture. Quantifying the potential impact of such demand-response is complex, in part because the intimate dependence upon the fine detail of climate and demand confounds the establishment of suitable benchmarks. However, one legacy of the ORIGIN project is a rich dataset that is being used to model the potential of residential demand-response at scale. Now that a year of end-to-end operation is complete, we are preparing a stream of publications that we believe will significantly impact on the understanding of residential demand-response, and the design of demand-response strategies.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
home1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
home3	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
home3	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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home1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
home3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
home1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
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home2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home3	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home2	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
home3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 1.5: Actuations at three homes in Findhorn over a one-week period in November 2015; for example, on day 1, the hot-water system in home1 was automatically turned on at 04:00, and turned off at 07:00.

As an example, Figure 1.6 shows outcomes from modelling based on ORIGIN climate and demand data, exploring how different scenarios (in terms of user engagement) can affect utilisation of local wind-generation, and also showing how this depends on forecast error. A '1 shift / 3 hrs' scenario, for example, indicates an engagement-level where participants typically make one demand-shift per day, and this shift would be within 3 hours of its 'normal' time (e.g. use of the washing machine may be shifted up to 3 hrs later or earlier, if sensible, based on renewables forecasts, but no other shift made). At the other extreme, '3 shifts / 6 hrs" represents highly engaged households; however that level of engagement is also achievable automatically, via actuation of water heating and/or EV charging.

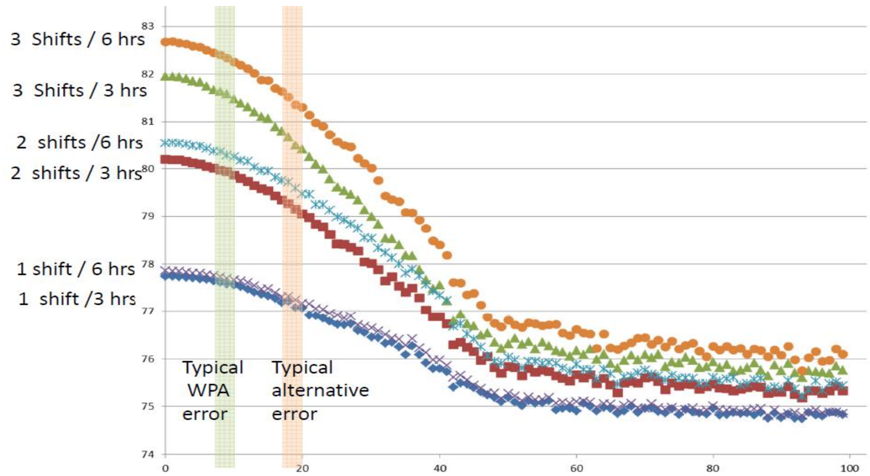


Figure 1.6: Modelling the outcomes of residential demand response scenarios as a function of forecast error, simulated based on Findhorn data. Vertical axis is utilisation of available wind energy, while horizontal axis is wind-speed forecast error. For scenarios refer to text.

Figure 1.6 starts to reveal some new understandings about the dynamics of demand-response, first disseminated at our Turin conference on 24th September 2015. In the assumed demand/climate regime for this simulation, *no-response* corresponded to 75% utilisation of renewables, and the figure reveals that even relatively poor forecasts can lead to a moderate improvement; more interestingly, we can see that engagement in times of multiple shifts is, on the whole, more effective than engagement in terms of large shifts in time; meanwhile, if we characterise a shift-per-day as a unit of engagement, we can see that one such unit leads to 2% extra renewables utilisation, provided that forecasting is suitably accurate. Such insight can be used, for example, to help interpret the outcomes of demand-response experiments in similar settings, for example, this suggests that it is reasonable to equate a 1% increase in renewables utilization at Findhorn with around 1 load-shift per day per every two households in the community. These and similar analyses are now under way, newly enabled by the completion of ORIGIN, and will be exploited to underpin new insights into the design and potential of residential demand response schemes, carried through into (i) further bids and collaborations (including several ongoing applications for further funding as discussed in the Innovation, Dissemination and Impact Section); (ii) a number of open-access academic publications planned for submission in 2016.

2. Demand Response

A critical feature of all built environment demand response programmes is the extent to which participation by consumers is required in order that the objectives are delivered. The smart grid approach envisages that consumers will undergo a transition that will see them play a more active role in grid management. The nature of the transition is as yet unclear. At one end is an entirely actuated system whereby the targeted load is the recipient of the information exchange (Figure 2.1). At the other extreme is an informational system that contains no actuation, whereby participants are informed of future events, are cognisant of the implications of their response and decide whether to act based on the information received. The opportunities that emerge over the next two decades stimulated by financial incentives, technological development and changes in social norms will determine the scale of the transition. Regardless of the type of demand response program deployed, participation is likely to be predicated on a consumer engagement strategy that encourages trust and provides clear information describing its aims and outcomes.

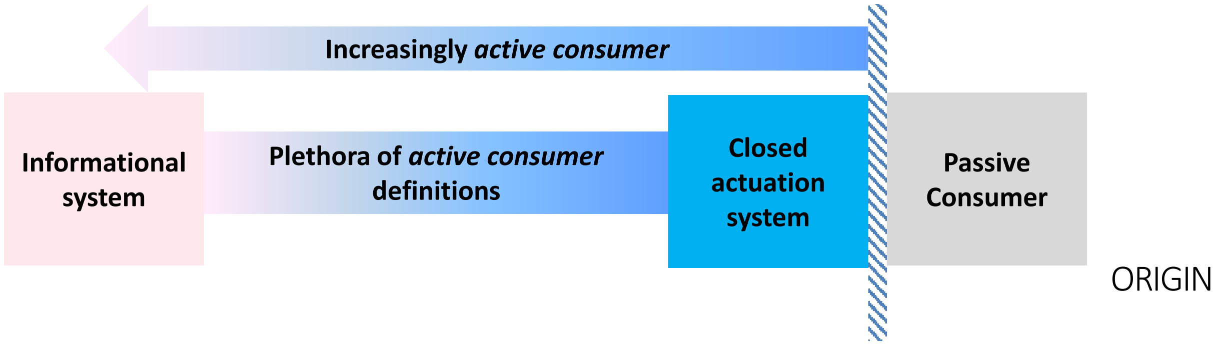


Figure 2.1: Boundaries of active consumer participation in a demand response system

2.1 User Interface

Description

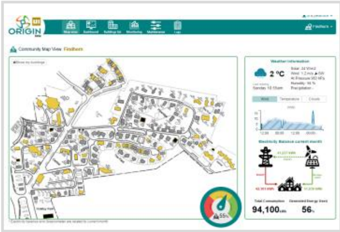
The ORIGIN project designed, deployed and assessed a multi-faceted web based User Interface (UI). It was used to convey information to residents in each community that would allow them to participate in the various demand response programmes initiated as part of the ORIGIN project (Figure 2.2).

Design

A novel, two-stage design approach was developed to create the UI. The first stage used a participatory approach to produce community-led design input. The second approach used structured assessment tools to measure user acceptance of the UI (Figure 2.3).

Participatory design workshops

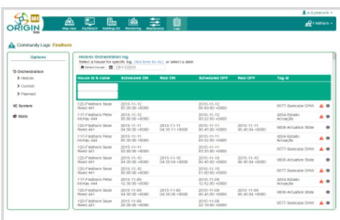
An End User Advisory Group (EUAG) was created in each community that took part in the participatory design workshops. The design objectives were presented to the EUAG at the start of the workshop. These were; (a) How would you like to be told about there being a surplus of renewable generation in your community? And (b) How do you know what the impact of your response has been?



Map View : depicts a map of each community and distinguishes the buildings that are participating in the ORIGIN project. The buildings are colour coded to provide a simple visualisation of those that are consuming more or less energy than the community average (using normalised indicators)

Dashboard: hosts gadgets that display forecasts of surplus generation and information concerning energy consumption. Each user can configure their own personalised dashboard, selecting those that provide meaning for them from thirteen different gadgets.

Building Level: users can drill down further to investigate, numerically and graphically, trends resulting from energy practice, for example, the internal temperature of the Magilla building in Damanhur (as shown). One user in Findhorn calculated that a roast chicken dinner cost £0.58 to cook.



Log Area: The UI also acts as a repository of actuated instructions sent to specific loads (here shown for two dwellings in Findhorn). The 'Logs' area of the UI also records usage statistics and system revisions

Figure 2.2: Overview of the ORIGIN User Interface

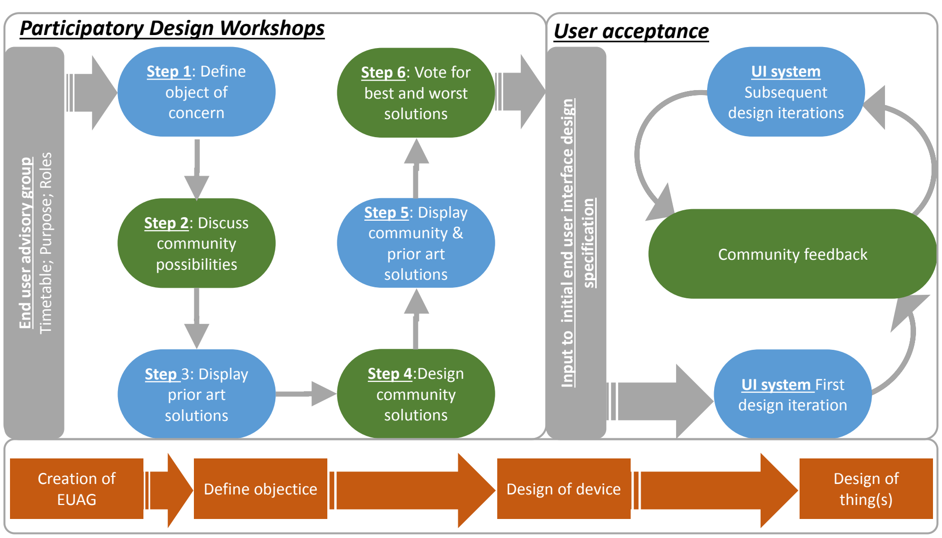


Figure 2.3: Participatory design methodology used for creating an ORIGIN HEM system

At each workshop the EUAG was split into different groups, each of which was tasked with developing a minimum of four different designs that would meet each of their objectives. The EUAG were presented with ideas that had been developed elsewhere and could conceivably meet those objectives. They then refined their initial designs, incorporating aspects of the existing solutions as they saw fit. The final phase of the workshops saw the participants vote on their favourite designs. These could be designs that were created during the workshop or existing, market ready solutions. The most popular designs were then used by ITI and HWU to design the gadgets displayed on the ORIGIN UI dashboard. Examples of popular designs that emerged from the workshops and were subsequently translated into dashboard gadgets are shown in Figure 2.4. The first is an ‘energy clock’ that provides a 12-hour forecast of surplus renewable energy availability. The other two gadgets provide instantaneous estimates of surplus, denoted by the health of a plant or the speed at which a horse runs.

Figure 2.4: How input from the community participatory design workshops was translated by the design team to create the ORIGIN UI.

User acceptance

The ORIGIN UI was deployed in each community in Nov/Dec 2015. Surveys were carried out in August 2015 to generate structured feedback that measured user acceptance. Two different methods were employed: the first used a technology acceptance model that defined perceived usefulness and ease of use, and provided indicators that could be used to improve both aspects in future design revisions; the second method measured the satisfaction delivered by the ORIGIN UI to the users using a model that gauged its pragmatic and aesthetic qualities.

The ORIGIN UI design approach was developed to maximise the likelihood that the information it conveyed was meaningful to the user group. In this it was partially successful with the users having a positive association with the UI. Its principal weakness was that its output was not perceived to be sufficiently task orientated and as a consequence was viewed as being neutral by users. Design revisions will further translate the information managed by the UI such that it conveys more explicit instructions (i.e. “do this; “stop doing that”) that are contextualised for individual buildings and users.

2.2 Informational Response

Electricity networks have had to absorb increasing capacities of intermittent renewable generation, a trend that is forecast to continue over the next two decades. This presents technical challenges for electricity grid operators as generation can now occur out of step with consumer demand for electricity. A number of technical approaches are being developed to solve this problem e.g. distributed storage, smart appliances, actuated demand response. The development of the active consumer, capable of changing their energy practices to better match this intermittent output, is also being promoted in addition to this basket of technical solutions. There is an extensive body of research that suggests that this form of active consumer will only emerge when environmentally committed practices become normalised in society. The ORIGIN project deployed informational demand response systems in intentional eco-communities where this normalisation has already taken place. It could be argued that the results achieved here represent a *change potential* for the active consumer approach. In the ORIGIN project, demand response to increase the use of surplus renewable generation was encouraged by providing participants with forecasts of its availability. This was incentivised in the Findhorn pilot trial using a dynamic wind tariff that linked the price of electricity to forecasted surplus generation from the local wind park.

Response/Impact

Changes by community participants to their energy practices resulted in only modest increases in the consumption of locally generated renewable electricity. In Damanhur self-consumption of building integrated PV systems was increased by 3.0%. The change potential of the dynamic wind tariff in Findhorn was estimated to yield an annual demand response of circa 40MWh, equivalent to 2.9% of generation from the community owned wind park. Washing machine use is widely seen as a load suitable for shifting. The informational system trialed in the ORIGIN project indicated that circa one washing machine cycle in five could be shifted via user participation to be coincident with surplus electricity generated from local renewable sources.

Consumer engagement

Overall, participation rates were found to be high in comparison with similar trials. For instance, 47% of households in Findhorn actively responding to the dynamic wind tariff at some point during the six month field trial with 21 % active throughout. Evidence of response fatigue was found in each community with peak response rates occurring after three months of the field trial. Consumer engagement strategies were found to play a significant role in determining the impact of the informational demand response initiatives. The ORIGIN project sought to create local champions who then became trusted advocates of the project in each community. Evidence was found to suggest that the absence of this localism caused the notion of demand response to disappear from community consciousness. Energy practices quickly reverted back to their original state. This underlines the difficulty of achieving firm, long lasting changes through a purely informational approach.

Time dependent demand response

Load shift behaviour was found to be a function of the time of day with periods found where participants were either unable or unwilling to alter their energy practices. This was most marked in Findhorn where surplus availability from the wind park could occur throughout the day compared to Damanhur and Tamera where surplus from PV systems was restricted to daylight hours. For instance, in Findhorn the maximum load shift potential of 0.19kWh/h (40.5% of the demand) occurred at 09h00, whereas demand remained largely unaltered between 00h00 and 08h00 (Figure 2.5). This time dependency resulted in 28% of the low tariff events, offered as a consequence of forecast surplus, occurring during periods where demand was unresponsive.

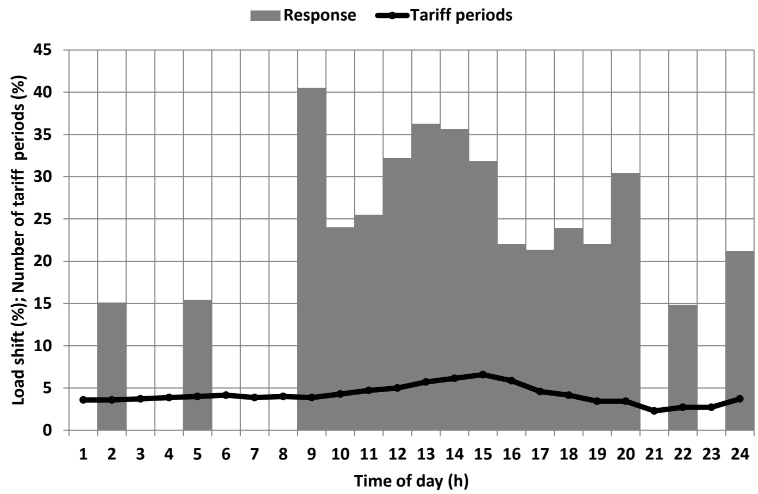


Figure 2.5: Average demand response of continuously active participants disaggregated by time of day

Forecast error

Errors occurred with the forecasting of surplus availability. This occasionally caused a discrepancy between the forecasts of surplus and actual surplus being available. For instance, in Findhorn 69% of the total shifted consumption was coincident with measured surplus wind generation and therefore contributed to an increase in local consumption. This discrepancy has economic and consumer engagement consequences. The most consistent feedback received from participants referred to situations where a surplus had either not been forecasted or has been forecasted erroneously.

Path dependency

In each of the ORIGIN validation communities energy consumption was significantly lower than the national average. For instance, normalised electricity consumption was 40% and 57% of their national average in Tamera and Findhorn respectively. The scale of demand response found in Findhorn correlated with consumption level in each dwelling, with higher consumption providing greater opportunity for load shifting. This presents a path dependency policy dilemma. If measures to create an active consumer are prosecuted alongside more long standing policy initiatives to encourage energy efficiency, the success of the latter may reduce the chances of the former emerging.

2.3 Activated demand management system

Actuation algorithms were developed and either modelled or deployed to allow switching of loads to better coincide with local renewable generation while meeting user requirements in various situations including: space heating and hot water loads; electric vehicle and battery charging loads. Remote control hardware and software infrastructure was implemented in a number of test cases that enabled these ORIGIN algorithms to demonstrate ORIGIN remote control of loads. The objective of the ORIGIN algorithm was to shift timings of the loads to better match with local renewable generation while ensuring end user demands were not compromised. A variety of different approaches to algorithms are possible including detailed physical modelling, purely statistical modelling, statistical meta-modelling, and combinations of these approaches.

The largest electrical load shifting opportunity identified was the Findhorn electrical loads for space and hot water heating in electrically heated dwellings. The renewable generation associated with these space and hot water heating systems included both electricity generation from wind and PV and also hot water generation from solar thermal panels. Two different approaches were used to shift the thermal loads to make best use of these renewable resources; (a) predictions based on a detailed physical thermal model of the system and (b) predictions based on a statistical model of the system.

Thermal Model Predictive Control of Space and Hot Water Loads.

A physical model based control algorithm has been developed and deployed for space heating and hot water load shifting. This algorithm can be run within a community optimisation system as in the ORIGIN project, or could be implemented at an individual system level. The algorithm is designed to accommodate hybrid energy systems with solar thermal inputs and with backup heating from a variety of sources such as heat pumps, biomass or gas. The energy system characteristics are a critical input to the model.

The flowchart for the algorithm is described in Figure 2.6. The algorithm quantifies load shift opportunities and then selects the best option based on the chosen optimisation criteria. The algorithm has been demonstrated in a number of Findhorn dwellings during a summer period where space and hot water requirement were met by a combination of a solar thermal hot water system and an electric boiler. Dwelling comfort criteria was met with significantly reduced requirement for the electrical boiler. When this load was required ORIGIN control was able to shift it to time periods coincident with surplus generation from the local wind park. The algorithm was therefore able to prioritise at a discrete building integrated, and a distributed generation level.

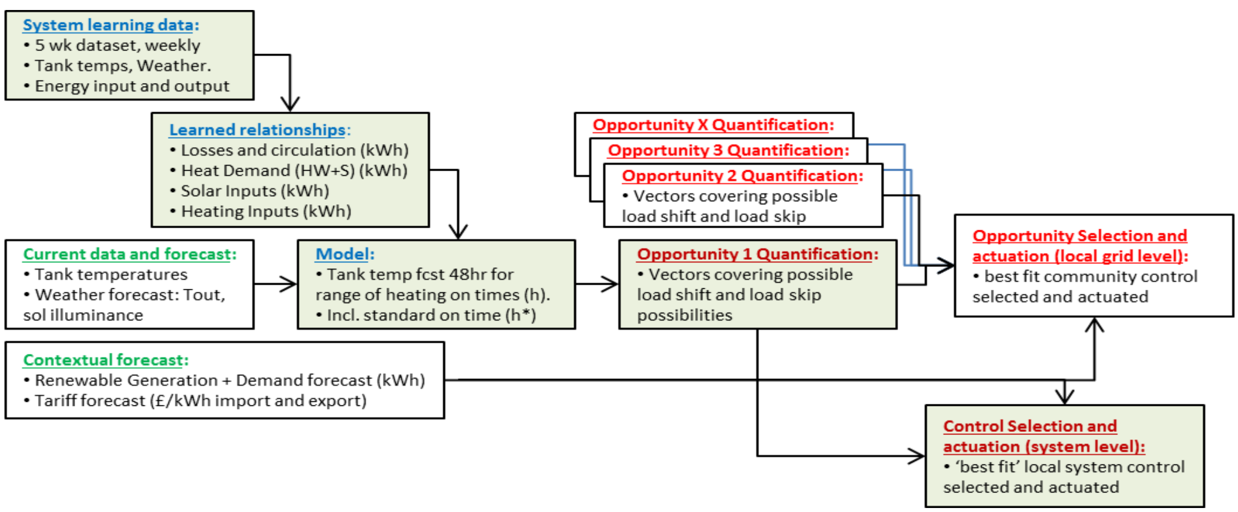


Figure 2.6: Flowchart for the thermal model predictive control algorithm

Statistical Predictive Control of Space Heating and Hot Water Loads.

A statistical modelling approach was also developed and demonstrated for the same dwellings. This statistical algorithm approach was designed to operate with significantly less initial input criteria, for instance energy system details were not needed. This reduced the technical inputs required for deployment or replication. The field trial of this approach took place between July and October 2015 and gave very positive results. The percentage of electricity used by the dwellings during this period from renewable sources increased from 13% to circa 40%.

Remote Control of Non-Thermal Loads

The potential for synchronisation of non-thermal loads with renewable generation was also identified. The Tamera site was a good example as curtailment of PV generation during the day in combination with grid imports in the evening and overnight indicated a large potential for improvement. The ORIGIN algorithms and hardware have been developed for these applications and initial testing carried out demonstrating the operation of the ORIGIN approach and benefits.

Modelling the Potential Impacts of Load Shifting

The testing for the remote control of loads was necessarily limited. The wider application across the demonstration sites was modelled. For Findhorn the reduction in grid electricity that would be realised by implementing the ORIGIN algorithm to shift space and water heating loads in the 38 dwellings with solar/electric heating systems would be 12%. In Tamera, optimised energy system control based on ORIGIN forecasts would eliminate the curtailment of the existing PV array resulting in output equivalent to that provided by 7kW of additional PV capacity. This equates to a 22% increase in output.

Discussion and Conclusions

Both of the 2 demonstrated approaches to thermal load shifting piloted at the Findhorn Community gave very positive results:

- Increased utilisation of solar thermal inputs and reduction in overall electricity use.
- Increased utilisation of renewable electricity instead of grid electricity.

The demonstration periods were of the order of months, but during these trial periods the algorithms demonstrated that backup heating was reduced by up to 50%, and that where backup heating was available, co-incidence with renewable electricity generation could be increased by a factor of 3.
To quantify the performance of these algorithms over the course of a year the results from these orchestrations were input to the Community model. The deployment of the ORIGIN automated control methods to the 38 dwellings with this system type in the Findhorn Community was modelled. The results showed a potential reduction in annual grid electricity imports from 519MWh to 454MWh, a 12% reduction.

These ORIGIN thermal load shifting algorithms have been identified as having wider applicability across the ORIGIN Demonstration sites such as: maximising solar thermal inputs and minimising backup heating requirements in Damanhur Nucleos solar/biomass systems, in Tamera solar/gas hot water systems, in Findhorn solar/biomass district heating systems. There is great potential for replication and future deployment of the developed algorithms in Communities or in individual systems. For example for future investment at Findhorn a district heating system combined with an ORIGIN controlled thermal store, solar and heat pump systems was identified as having high potential for maximising local use of local wind generation. In individual domestic solar systems there is currently non-optimal operation due to the use of fixed control regimes, the ORIGIN system could be deployed at an individual system level to address this problem. The ORIGIN actuation solutions developed would appear to have wide future application potential across the sector.

2.4 Summary Energy and Carbon savings

In conclusion, the demand response potential of communities and neighbourhoods is highly variable and depends upon the energy resources of the community in question. (Table 2.1).

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 trialed 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 2.1 Summary of demand response potential at each of the communities from different project scenarios.

3 ICT Hardware System

The ORIGIN system consists of a number of Field Devices providing information and receiving information from the ORIGIN CEMS (*Community Energy Management System*) see figure 3.1. This is the figure on the left-hand-side in Figure 1.1, which is used to contextualize the end-to-end operation primarily from the perspective of the software system. In this section we focus on the hardware aspects.

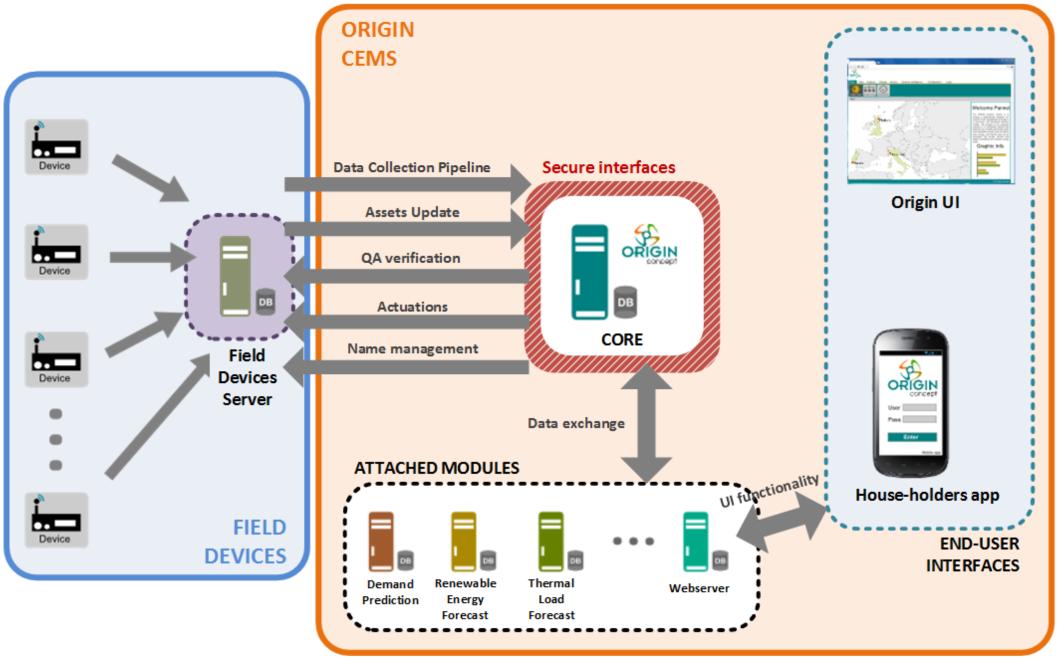


Figure 3.1 - ORIGIN platform high-level architecture

The field devices include all the devices installed in the field to monitor/control the community; the communications and integration architecture; and the Field Devices Server, which manages and reads them. Approximately 1100 sensors, transmitters, hubs, heat meters and actuators along with a weather station have been installed in in over 70 buildings in the three pilot sites allowing detailed and comprehensive energy maps to be created for each at a load, building and community level. These encompassed renewable energy supply, grid import and exports, energy storage condition, space conditioning, domestic hot water usage, appliance usage, non-residential loads, thermal comfort and occupancy. This rich array of data was used to identify key features that influenced demand response and individual and community energy practices. This detailed characterisation was necessary in order to allow simple, efficient algorithms to be created that selected only the required information to deliver the objective function. An example of this is the statistical model that was developed to actuate thermal and domestic hot water systems in Findhorn. These were installed in dwellings which contained 33 different sensors. The knowledge provided by these sensors with respect to consumption and supply patterns allowed models to be developed that required only two sensors to inform the actuation of space and hot water heating.

One of the advantages of this system is that the level of monitoring can be tailored to suit requirements and a simple (see figure 3.2) and or advanced system (see figure 3.3) can be used.

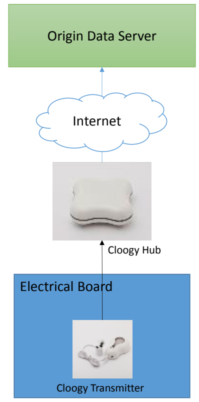


Figure 3.2 - Basic Monitoring Module Layout

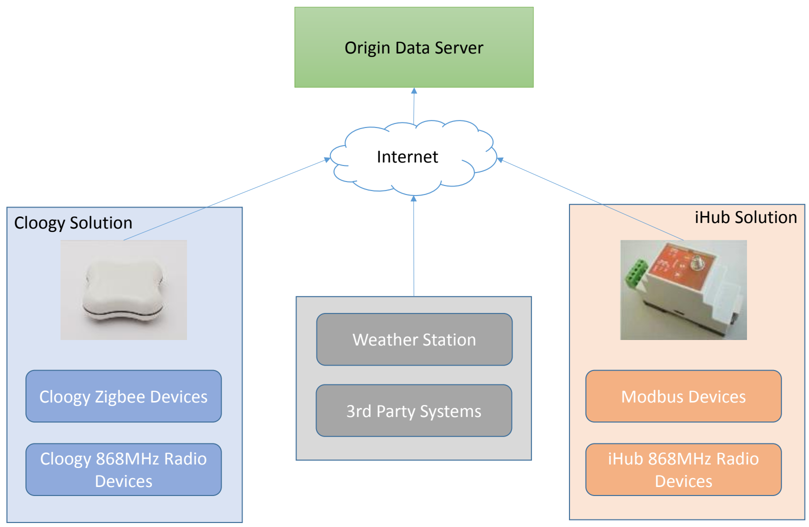


Figure 3.3 - Advanced Monitoring Module Layout

The ORIGIN Community Energy Management System (CEMS) processes the information coming from the Field Devices block and analyses it. This analysis generates forecasts and predictions, which are used later to orchestrate the energy in the community. This approach has worked. The internet is used to send and receive information and some of the field devices are operated by batteries. During the project a number of enhancements have been made to the hardware used and these are detailed further in the exploitation section of the report. These enhancements increase the reliability of the system, allow more environmental parameters to be measured in a domestic situation and allow the system to interact with third party inputs. Also, development work was done to enable the field devices to be used with UK plugs and to eliminate battery use where possible.

Consumer feedback during the installation phase of the project made it clear that the number of individual sensors that were being installed would not have been tolerated with a commercial installation. Rather than being disparate, systems would need to be plug-and-play required that can easily be retrofitted into existing dwellings, ideally without the need for specialist installers.
The project as a whole suffered from missing data issues mainly caused by wireless connection of sensors. Systems were not capable of providing ride through monitoring capability in response to connectivity being lost.

4 Communities

4.1 ORIGIN Community Legacy

ORIGIN has developed and installed a bespoke energy monitoring and demand response system in each of the three validation communities. The hardware and forecasting remains in place at the end of the project and will continue to be supported by Heriot-Watt, VPS and ITI following the completion of the work programme for a period of one year. While the support will be limited by lack of resources the Consortium are actively seeking funding for follow on projects from ORIGIN to move the technology towards commercialisation and further demonstration of its effectiveness. Details of the attempts to secure funding are given in the Innovation, Dissemination and Impact section of this report.

In effect the legacy of the project in the communities is that they have inherited an operational participatory demand response system that will be supported by the partners for a year while attempts are made to secure continuing funding of ORIGIN and other energy innovation projects. The Validation Communities provide three community scale "living laboratories" comprised of the ORIGIN ICT systems and, importantly, an enthusiastic, energy conscious population. The resulting academic resource is of high value to the ORIGIN project researchers and other interested third parties who are interested in energy consumption and demand management at a community scale.

Participatory Demand response is only possible through clear communication of energy information to the participants. The bespoke user interfaces created for each of the communities provides them with awareness of their energy consumption and community generation; however of equal importance is that the project community engagement has educated them in how to make informed energy lifestyle decisions. Consumers can reduce the import of energy to their community by maximising the coincidence of energy demand with renewable generation.

4.2 Living with ORIGIN

The Findhorn Community

Impact and Impressions of Living with Demand Response in Findhorn

The following observations and comments were made by the residents of Findhorn to summarise the impact of ORIGIN upon their lifestyles. Each comment is followed by a brief response.

"We discovered that creating the monitoring array for each household out of various kinds of kit - mostly supplied by ISA but not all of it was more time and talent consuming then had been envisioned in the written grant proposal" – This supports the conclusions and experience of the full consortium in installing and maintaining the ICT infrastructure and data feeds. The fact that an "off the shelf" domestic demand management system was not available meant that a bespoke ICT system had to be designed and installed by the consortium in each community. Reliance on third party broadband signals led to frequent data gaps and the need to aggregate hardware from different sources, and different countries into an integrated system led to reliability and compatibility issues.

"Installing in existing houses - some of which were already high spec in their controls (East Whins & Centini) added complications which had to be negotiated. New build would be much much more straight forward to install" – This comment is self-explanatory and raises the difficulty of retrofitting sensors and actuation devices into existing buildings.

"Sending so much information down our less then robust private community network caused data stoppages - rather often ??" - This is a fundamental problem associated with appending a sensor driven demand response ICT infrastructure upon communications systems design for other purposes and applications. A successful demand response system will either have a dedicated broadband service, or highly robust communications system, or accept and adapt to frequent missing data problems.

"Having battery powered sensors meant extra labour to frequently change batteries and would use plug-in from the beginning in the future; ditto UK plugs would have been nice " – This again reflects the need for future development of a novel ORIGIN ICT product that can be installed in a plug and play fashion and is tailored to the local infrastructure. In Project 3, the energy catalyst proposal, described in the Innovation, Dissemination and Impact section, VPS, HWU and FF will develop such a device.

"It is likely the quantity of sensing was over specified - but now the research team learned what is really needed and what is not" - This is a valid point for a commercial ORIGIN system and will be addressed by continuing research effort post ORIGIN.

"The EMR issues were not fully explore and people are again expressing concerns about it in our community ??" – Some members of the Community had fears concerning electric fields and their health effects. Any widely deployed demand response system will require clear communication to the end users.

"The Dashboard and Tariff game attracted some interest - it really needs longer to become the 'new normal' to consider the renewable surpluses (and we hope we get that chance with further grants and dashboard time) " - The continuation of ORIGIN through further funding opportunities will enable the "dashboard" user interface to embed itself in the daily routine of the communities. It was apparent during the research that the participants responded positively to community engagement activities. Without engagement activities and reminders of the purpose and benefits of the demand response system participation rates dropped significantly.

"Getting the feedback - the dashboard - even more accessible on phones and tablets - one click - would help the older or v busy populations" – This is a good point and the need for an "App" has been discussed on several occasions by the consortium. It is a relatively inexpensive expansion of the user interface but would open up new business models and increase the pool of potential participants.

"Over all the awareness of our renewables, our surpluses and the grids need to balance and our part in the global project has landed with a high % of the community residents whether they participated directly or not; Also with our guests visiting for days or weeks (few thousand a year) who see the public display and at least catch a glimpse of bigger picture" – With or without demand response the provision of energy information, in an appropriate format, to communities and the public enables them to make informed decisions regarding their energy lifestyles.

"We - the team at Findhorn - really enjoyed the doing the project and meeting and learning from the project partners - further research by students of HWU and UoS is expected and welcome xx" – The data and research from ORIGIN will provide many opportunities for energy related student projects in Findhorn, Damanhur and Tamera in the coming years, facilitated by the excellent working relationship that has been developed between the Communities and the other consortium partners.

Extension and exploitation of ORIGIN at Findhorn

The Findhorn Community has the advantage when expoiting the ORIGIN project of being based in the same administrative region as HWU and UoS. This enables them to apply for research funding that is only available in the UK (and Scotland) with the support of two of the main academic partners in ORIGIN. To date this has resulted in four planned and/or submitted grant applications in the energy field with the intention of continuing and enhancing the legacy of ORIGIN. These projects:

1. An application to CARES (Energy Saving Trust) for actuation of 29 buildings in the Park has been submitted at the end of October 2015. FF is the applicant and most of the money will be spent by Heriot Watt University (HWU). If successful, the grant will run for a year from March 2016. The project funding will total £100,000.
2. Construction Scotland Innovation Centre (CSIC) is interested in continuing the activation work, potentially initially funded by CARES. Work packages, using ORIGIN as the starting point, have been discussed with the funder CSIC. The nature of their support will depend upon the application for CARES funding mentioned above as the intention would be to run two complementary projects. FF envisages an application for total funding of £200,000. The applicant will be FF with HWU, Strathclyde University and Auraventi as consortium partners.
3. The Findhorn Foundation College (FF) are currently working as a partner with HWU and Virtual Power Systems (VPS) for an application to the Energy Catalyst Innovation Fund of the Technology Strategy Board (UK Government). This funding scheme provides up to £200,000 in total support. VPS is the applicant as the project involves developing a “product” that simplifies the installation of ORIGIN systems in buildings. The application was submitted to the UK’s “Energy Catalyst” funding scheme on the 25th of November 2015 and the grant would run for a year from the first of April 2016 if funded.
4. The Findhorn Park is now an excellent field test site for demand led energy management system trials as ORIGIN has provided a valuable community laboratory comprised of 100s of sensors installed in 70 buildings and an enthusiastic body of participants. HWU and UoS are planning to submit a grant application to the University Research Council for ~£500,000 in early 2016 for innovations in energy management systems to exploit the ORIGIN legacy “living community lab” in Findhorn. FF would manage and maintain the field trials as a consortium member.

   In addition FF has been approached by the NHS Highland Research, Development & Innovation Office in Inverness (Centre for Health Science) to join the team working on the development of a new hospital complex on the Raigmore Hospital site for the NHS. This could involve ORIGIN energy management systems and waste minimisation.

The Tamera Community

The Tamera Community proved to be a very low energy demand community during the project with a total annual energy demand equal to a small fraction of the other communities’. This is partly due to the philosophy and lifestyle they choose to follow and the environment in which they live. However such low energy communities provide little opportunity for energy demand response per person due to the low base demand. This is particularly the case for automated actuation and the project only identified the charging of electric batteries, agricultural pumps and electric vehicles as potential options for automated demand response scheduling.

One particular anomaly identified by the research team at Tamera was that the electric battery system was set to charge itself during the night leaving no opportunity for storage of their PV generation in the morning. This effectively greatly increased the curtailment of their community based PV generation. The ORIGIN energy monitoring system identified this problem and enabled a solution to be found.

Impact and Impressions of Living with Demand Response in Tamera

The following observations and comments were made by a representative of the residents of Tamera to summarise the impact of ORIGIN upon their lifestyles. Each comment is followed by a brief response.

"We are happy to have worked together with the consortium in the ORIGIN project. It was our first FP7 project and we learned a lot by doing it. Without exception we found the project partners professional, helpful and committed." - Although a non-technical comment this does highlight the good relationship ORIGIN has engendered between the communities and the rest of the ORIGIN consortium.

"We are not part of the Joint Venture mainly because it is quite far outside our core interests and we do not have the expertise to objectively evaluate the risks/benefits of continued involvement." – It should be remembered that the communities' ideals and goals do not always match closely to commercial exploitation of research and as a result Tamera have not become part of the ORIGIN Joint Venture.

"Regarding the content of the project: We feel it is very important to deeply consider the details of how the core principle of load shifting is implemented. Decentralised structures can lead to a resilient network - this is a direction which we would like to support and be a part of. The technology as it stands could also be used to reduce community autonomy and increase centralised control, a direction which we would consider unwise and unstable. " – This is a deep comment that cuts to the core of the debate surrounding centralised or disseminated control of energy systems. The majority of the demand response during the ORIGIN project involved the participatory demand response system based around the user interface and active decision making by the residents. In the smaller number of "actuated" demand response activities control was ceded to the remote system, however the actuated system required volunteers and at all times the occupants had the opportunity to override the control signals and essentially switch the system off.

"We intend to continue to use the current system for at least the next year and to stay in contact with the project." – This is evidence that the community consider the ORIGIN system to be a positive influence upon their energy lifestyles.

Extension and exploitation of ORIGIN at Tamera

As mentioned in the final community comment in the previous section, the Tamera community intends to continue to use the User Interface for the year following the project. During this time the user interface will be partly supported by ISA to enable the energy monitoring to continue to inform the system. In addition Heriot-Watt will continue to provide the forecasts to the ORIGIN system for the year following the project while the resources required are available. However this continuation is resource dependant and severe malfunction of the system may curtail the continuation unless other sources of funding are acquired.

One well defined possible extension of the ORIGIN system in Tamers is the electric vehicle charging system. This system has been built and shown to operate during the ORIGIN project. Heriot-Watt have applied for funding to improve the EV charging system within the Blackwood Grey Fleet to Green Fleet project which will create a more robust system if funded. This will enable HWU, ISA and Tamera to continue to work towards a commercially viable smart vehicle charging system.

The Damanhur Community

The part of this community engaged in ORIGIN was comprised of the Crea building and three "Nucleos". The Nucleos are effectively large buildings that provide homes to large groups of people from the community. They are not geographically adjacent to each other although they are linked by a common sense of community. The Crea is a three floor building housing a variety of businesses from artist studios and medical clinics to small offices and a restaurant.

The research team did not identify suitable energy devices for actuation during the energy audit and hence adopted a participatory approach to demand response in Damanhur. This involved community engagement at a "community" and a "nucleo" scale to encourage participation and explain the demand response system to the participant and the effect of their participation upon their energy demand. The importance of running community engagement events was reinforced by the project's experience at Damanhur when the main proponent of ORIGIN in the Community was unavailable to support the project for an extended period of time resulting in a corresponding lack of community engagement with the user interface. Having identified this, several members of the research team visited the community and in the following weeks a noticeable increase in participation was observed.

The dispersed geography of the Damanhur Community leads to a "nucleo scale" awareness of the specific local energy infrastructure and demand. However each nucleo has a weekly meeting at which the community discuss many issues related to sustainability. The nucleo known as "Magilla" are the most technically focused of the nucleos and reported that ORIGIN became an important discussion at the weekly nucleo meetings. Effectively this structure created a forum for the discussion of ORIGIN, and associated end-user engagement, enabling the community to disseminate and plan their demand response participation.

Extension and exploitation of ORIGIN at Damanhur

During the project the Damanhur community was introduced to the Department of Energy at The Politecnico di Torino (Polito) who hosted the ORIGIN conference in September 2015. Damnahur and Polito are exploring further possibilities for local funding in Italy, at a regional and national level to develop further the ORIGIN monitoring and forecasting system installed at Damanhur. They are currently evaluating the submission of a proposal to Innovation Poles, promoted by Regione Piemonte and financed by FESR and also to the specific call - Automotive, Intelligent Factory and Internet of Things managed by Regione Piemonte due out in 2016.

4.3 Community Recommendations and ORIGIN Design Process

Work package 6 involved the use of Community models calibrated by monitoring data to identify complementary technologies for the demonstration sites. Intended outcomes were:

- useful recommendations to the Communities to inform their future direction;
- to demonstrate how such modelling can be used as a design tool for integration of technologies, including the ORIGIN system, in future developments.

The complementary technologies and expansion scenarios investigated were identified based on Community input and Academic suggestions informed by analysis of ORIGIN monitoring datasets. Technologies investigated included: expansion of the deployment of ORIGIN thermal load shifting systems; electrical storage systems (Compressed Air, Flow Battery, Conventional Battery); optimized battery charging schedules; expansion of electrical generation (PV, Wind, Tidal); expansion of renewable district heating systems (Solar Thermal with Biomass or Heat Pump). Modelling was carried out at building level and community level using the open source ESP-r and MERIT software tools, and the commercial HOMER software which is commonly viewed as state-of-the-art in community level design.

Research was carried out to inform the Communities of characteristics and feasibility of each of the technologies. The suggested range of technologies and expansions was broad and this diversity was covered through a number of scoping studies. Both Damanhur and Findhorn are considering expansion of their biomass heat networks, background information on the carbon intensity of biomass produced heat from various supply chains was provided to inform these expansion plans, in particular the environmental impacts of local naturally air-dried wood fuel (chips or logs) were contrasted with those of internationally sourced artificially dried wood pellets, and the land required to produce wood fuel sustainably was highlighted.

Community recommendations: Findhorn

A design evaluation was carried out using HOMER software of realistic future complementary technical options for Findhorn with 75 buildings on a private wire network with a significant quantity of Wind and smaller PV, which currently could be described as 'net zero' but imports 45% of its energy demand from the grid. The evaluation considered energy autarky as well as financial criteria for best case (net metering) and worst case (zero value export) grid financial interactions. In the most autarkic combination grid imports were reduced to 0.8%, the largest battery storage evaluated gave the best results for autarky. For the worst case financial scenario only ORIGIN thermal load shifting was financially beneficial.

For the net metering financial scenario, increased wind generation gave financial benefit from exports, the largest storage option was financially unattractive. The financial benefit from wind generation in the net metering scenario could be used to offset other technologies and deliver 4% grid dependence with the same cost as the current situation, this could be viewed as a potential optimum. Securing long term financial arrangements was found to be key for planning the optimum path, it was recommended that these be determined and then analysis carried out with the created models.

Beyond the main modeling study, other expansion scenarios put forward by the Community included tidal generation in the nearby river estuary. A quantification of tidal resource, and modeling with tidal and addition electrical storage was carried out using MERIT software. Costs did not look attractive and environmental concerns would be potentially problematic in taking this forward.

Future community expansion plans include additional dwellings at Findhorn. The community were originally considering wood pellet plus solar district heating systems for these dwellings. The recommendation from the ORIGIN team was that this new development be designed to incorporate and maximize the benefits of the ORIGIN system, with a district network with significant thermal store, heat pump instead of wood pellets for backup heating, and ORIGIN thermal algorithm deployed within controls that maximize solar inputs and align backup heating with renewable electrical generation from PV and Wind. A funding proposal has been put forward for this system.

Community recommendations: Tamera

The Tamera energy flow analysis and HOMER modelling showed that a significant amount of solar electrical generation potential was being lost during the day. Opportunities to address this were identified, including optimization of the charging of the batteries, and shifting of loads into the peak generation times (ORIGIN control of water pumping, EV charging etc.).

Battery banks are charged from the grid with low tariff electricity overnight, no exports to the grid are allowed.

The model has been used to evaluate a range of scenarios, beneficial upgrades identified include: Orchestration through ORIGIN of the night charging from the grid to maximize storage available for renewable energy and minimize grid electricity; Orchestration of shift-able loads through ORIGIN when there is surplus renewable energy forecast; Addition of further electrical storage; Enhanced use of electric vehicle charging incorporating ORIGIN smart charging system; Water pumping synchronization and potential for hydro storage between reservoirs; Potential addition of wind generation; ORIGIN controlled refrigerated food store; Potential for ORIGIN solar thermal orchestration algorithm and display technology to minimize use of backup gas heating; Potential for anaerobic digestion of wastes.

Community recommendations: Damanhur

The Damanhur pilot site consists of a series of both domestic and commercial buildings. Domestic buildings are residential units called "nucleos" with approximately 20 to 25 residents in each. These building are heated using biomass boilers augmented with solar hot water systems. Electrical demand is met by a combination of large solar-PV arrays and grid electricity. All the buildings are grid connected allowing any surplus renewable electricity generation to be exported to the grid. Damanhur are actively looking at the upgrade of the Crea gas heating system and have been using the ORIGIN data to help inform their decision, they are also looking into electrical storage options.

Damanhur electrical models were constructed in HOMER. Modelled scenarios that showed potential benefits for renewable generation and self-consumption included similar options to those reported for Findhorn and Tamera such as: Electric storage to allow greater self-consumption of solar PV generation; ORIGIN orchestrated electric vehicle charging (and expanded EV use) to enhance self-consumption of solar PV generation; ORIGIN orchestration of person controlled electrical loads; Addition of wind generation; Addition of hydro generation with hydro pump storage; Expansion of Crea district heating to adjacent nucleos and replacement of gas with ORIGIN orchestrated biomass / solar system with thermal store, fed from local sourced naturally air-dried biomass; Expansion of Crea district heating to adjacent nucleos with ORIGIN orchestrated biomass CHP / solar system with thermal store; Solar biomass hot water systems in all nucleos to be orchestrated by ORIGIN algorithm and display technology to maximise solar and minimize backup heating requirement.

Addition of wind and hydro electricity generation in combination with electrical storage was identified as having the potential to provide a better year round electricity supply. There are probably sufficient local hydro and wind resources to make this feasible. The biomass options need careful consideration of the biomass supply chain as discussed above. The CHP option also needs careful consideration and comparative lifecycle carbon and financial assessment including maintenance and replacement etc.

Long term electrical import and export tariffs should be determined and then optimum system performance determined from the models.

ORIGIN Design Process

The Community level design process using HOMER and MERIT software was demonstrated and discussed, and suggestions made for future applications, including the use of more advanced optimization and robustness analysis, and the incorporation of more detailed time-of-day tariff scenarios. This community level design process needs inputs from more detailed design assessments of thermal load shifting from building and system level modelling tools such as those developed in ORIGIN WP4. The ORIGIN optimization software itself has potential to be used directly for assessment of technology options and also evaluation of alternative orchestration algorithms.

Conclusion

The ORIGIN monitoring data was used to inform building, system, and community level models and generate community energy system recommendations. The core of this work has been the use of modelling methods calibrated by ORIGIN data to inform decisions on future directions for the demonstration sites but more importantly to demonstrate the methods that can be more generally applied to inform future strategy in local energy networks. The range of options for potential upgrades is large. Scoping studies were undertaken to answer questions of specific interest to the sites, these have provided useful insights for the demonstration communities, and for future applications of ORIGIN elsewhere. Financial arrangements over longer term should be secured then optima determined.

4.4 Energy Characteristics of People and Communities

The three communities in the ORIGIN project each operate with distinct attitudes, lifestyles and philosophies that differentiate them from each other. These diverse and unique contexts have revealed some key results around the importance of understanding context within Demand Response (DR). Findhorn households have strong similarities with mainstream ones; their community way of living could be compared to co-housing; Damanhur residents live in communal buildings with individual sleeping areas, but with shared living and cooking spaces, an arrangement which is not dissimilar to student accommodation; Tamera community members are very low energy consumers with a strong communal lifestyle. They also have a large number of visitors to their site. The different setup of the three communities, as well as the lifestyles and attitudes of individual people within these communities have been shown to have a significant influence not only on people's willingness to be actively involved with demand response, but also their ability to play their part in it. For instance, Tamera's very low consumption lifestyle means there are very few loads that individuals can shift. Furthermore, the energy consumption behaviour of the large number of visitors, who are uninformed about the communities DR goals, outweighs that of the permanent residents.

Context is an important factor in an individual's ability and willingness to respond to informational driven DR. The ORIGIN project has shown that there are a number of factors that affect a household's response to informational signals to shift load. These can be broadly categorised as: user's needs, desires and motivations; user experience and acceptance of the DR informational systems and their emotional (pragmatic and hedonic) response to them; user work-life balance and their ensuing occupancy patterns; the presence of community advocates; the existence of financial incentives. The broad range of these factors highlights how critical it is, in the design of DR programs, to look beyond just the technology and actively consider human behaviour and how it can be influenced in order to achieve significant and reliable shifts to match renewable generation.

In order to understand the context of the participating households in the ORIGIN project, a collection of methods were applied in the initial design of the program. These included behavioural surveys, revealing the energy consciousness of participating households, as well as participatory design workshops, which highlighted end-user motivations, concerns, priorities as well as people's preferential channels of receiving information. Such methods can provide useful data for the design of the technology, which through multiple iterations, prototype trials, user-feedback and refinements can potentially lead to a product that is both simple and desirable, meeting the user's needs. However, there are aspects of behaviour, which might be more effectively revealed through observation. Two statistical approaches that were developed through the ORIGIN project make it possible to explore some aspects of user behaviour through interpretation of the monitored data. Methods of this type are very powerful, as they provide quantitative approaches to uncovering real and dynamic patterns in end-user behaviour (rather than reported patterns captured on the day of an occupant survey); they can be used in combination with survey and other knowledge to imbue information with user specific meaning and provide it in a timely manner considerate of a user's lifestyle routine.

One of the methods developed by ORIGIN is a statistical approach of classifying patterns of load profiles through analysis of the overall household consumption data. It was found that there are a finite number of distinct daily consumption profiles, which on a given day a user might be following, depending on their lifestyle. The method gives an indication of the consistency, variability and magnitude of household energy consumption behaviour parameters, which could be used to give an indication of the likelihood of demand response. Further analysis of this data in combination with specific knowledge about a household (such as how many people live in the home, the occupation of the occupants etc.) may allow a deeper understanding of how profile types relate to lifestyle and therefore a household's ability to respond to a request to shift a load.

This statistical approach is complemented by another method developed during the ORIGIN project that combines multiple sensor data to infer the occupancy of a household. Behavioural DR is limited by people not being present at home at time of energy surplus, and therefore understanding likely patterns of occupancy gives an indication of whether a response is physically possible. The occupancy pattern of the building also characterises the work-life patterns of an occupant, for example it reveals when a person leaves home and the number of hours they spend out of the house. It allows information to be contextualized, so that a message could be sent to a person just before they usually arrive home if there will be an opportunity for load shifting that evening. Knowing occupancy enables the system to only notify occupants when it is likely to be possible for them to respond. There are other benefits too, for instance by combining occupancy with the aforementioned statistical approach for determining load patterns, it would be possible to determine how good a candidate a household is for DR (through the degree of flexibility of their load use and the variability of their occupancy at different times of day).

If the insights from methods such as these are combined, a rich understanding of user behaviour could be produced. A potential use of this is as follows: the identification of users who are most likely to be able to respond to DR signals, who might then be offered a dynamic tariff by their energy retailer. The occupants save money by responding to price signals from the retailer and the retailer makes money by having a collection of households from which it is confident of achieving a concrete response.
People have different preferences of channels for accessing information. Having only one route for information delivery therefore limits the reach of an informational demand response system. Furthermore, any information rich system needs to take into account the frequency with which people will actively look for information; with the survey showing that in all three communities the majority of people tended to search for information on average only once per week.

5 Economic viability of community demand response

One of the key objectives of the ORIGIN project was to develop a community scale demand response system that would increase self-consumption of locally generated renewable energy and would be replicable. Its replicability would be predicated on whether its costs and performance were able to deliver a viable business model. Using the Findhorn community installation as an example, costs and revenue streams accrued by the community as a consequence of load shifting were developed to test this viability hypothesis.

The model assumed that all economic benefits attributable to the ORIGIN system would be acclimatised within the community. It further assumed that the only revenue stream to which the system could gain access was conventional electricity trading between the community and the distribution network operator (DNO). Hence the cash flows in the model collapsed to the costs of importing electricity from the DNO and the revenue accrued from selling the DNO surplus electricity from the community. These took account of the day/night, import/export tariff arrangements that existed between the community and the DNO.

5.1 Revenues

Two strategies were considered in the model; (a) a financial optimisation approach which sought to maximise revenue and (b) optimised self- consumption which sought to maximise use of the surplus generation in the community. Only marginal differences were found in the economic performance of the ORIGIN system when operated using each strategy. Substantially higher degrees of load flexibility were required to achieve financial optimisation with only marginal improvements in revenue. The application of the optimised self-consumption strategy resulted in the ORIGIN system delivering a maximum financial outcome of circa £13,000pa, or a 10.9% increase in self-consumption.

5.2 Increased self-consumption

The load shift potential of the various different demand response initiatives applied in Findhorn are summarised in Sections 2.2 and 2.3 of this report. The actuation of electrified heat and hot water systems was considered in greater detail to understand whether the revenues delivered by the project created a viable business opportunity. Two different deployment possibilities were evaluated:

(a) The field trial indicated that if applied to all 38 appropriate buildings in Findhorn self-consumption would increase by 6% (using the more conservative scenario estimate detailed in D5.7). This would provide estimated annual revenue of £7,100.
(b) In order that this demand response approach could deliver the aforementioned 10.9% increase in self-consumption, and therefore achieve the full £13,000 benefit, a further 30 dwellings would be required to participate (i.e. in 68 dwellings in total).

A discounted cash flow assessment was carried out to consider each of these deployment possibilities using the following assumptions:

- The Capex per dwelling is £100 to include a voltage clamp, temperature sensor on the thermal store, actuator, hub and router
- The Opex per dwelling is £135 which incorporates Wi-Fi contract (£60 pa), software licensing costs including server rental (£75 pa)
- The discount rate applied was 3.5% (as used by the UK Government)
- A positive cash flow was delivered after 5 years and 4 years for the 38 and 68 dwelling deployment possibilities respectively.
- Annual positive cash flows of circa £2,000 and £3,800 were estimated for the 38 and 68 dwelling deployment respectively

The results suggest that a viable business case can be made for this type of community scale demand response initiative, all be it with small revenue streams. These were generated as a consequence of the community being able to trade as an entity with the DNO which was possible at Findhorn because of community ownership of local network assets. European energy markets are in flux in response to the transition to a low carbon economy and this may create additional opportunities to bolster the revenues seen here, widening the applicability of the approach.

6 Future energy markets

The ORIGIN energy management system provides communities with a technical energy management tool to monitor and orchestrate energy consumption and generation at a community level. Communities and their residents can

- shift and/or reduce energy demand,
- increase the share of low carbon or locally generated electricity
- optimise the cost-benefit relationship for their community energy supply system

This technical solution will only have a chance for a broad roll-out, if it is combined with business models and market solutions leading to financial or other benefits for each of the involved actors (customers, electricity supplier, grid operator etc.).
The more traditional options for value creation are:

(a) Energy savings because of increased awareness of consumers;
(b) Electricity purchases at lower prices, e.g. lower tariffs in surplus periods;
(c) Self-consumption of electricity generated locally;
(d) Lower costs for other energy resources.

Due to the rising share of renewables in the generation mix, the energy sector is undergoing major changes. A successful transition of national and European energy supply systems incorporating a high share of sustainable energy resources involves the empowerment of smaller, distributed generation systems. Currently we are at the beginning of opening up markets for smaller participants in energy trading and redefining the requirements of system services to allow new service providers to enter the market. Integrating the provision of smart services in products like the ORIGIN energy management system will lower the technical and motivational barriers for smaller actors to participate. This allows communities with significant renewable generation to generate additional financial and systemic benefits by offering services and products to the national grid or other third parties such as:

- Energy trading (all countries, spot trade, intra-day OTC, …);
- Primary Reserve / Frequency Response (Germany, UK);
- Fast reserve /Secondary Reserve (Germany, Italy, Portugal, UK);
- Tertiary Reserve / Short Term Operating Reserve (Germany, Italy, UK);
- Regulation Reserve / Replacement Reserve (Italy, Portugal);
- Switchable Loads (Germany).

However, our findings show that currently there is no clear path to mass market penetration and economic benefits for residential customers are still low and result in small annual budget savings. Technology and implementation costs are high due to the lack of economies of scale. As a result, emotion and lifestyle factors currently are reasons to invest in demand response for private customers. In Findhorn, our survey indicated that 50% of those surveyed would pay £5 / month for the service.

However, commercial and industrial customers, with bigger loads, can see a clearer business case for demand response and generation prediction.

The intermittent nature of renewables means that an ORIGIN system combined with actuating distributed storage devices such as heat pumps, thermal stores and battery systems is a promising way forward as this enables a community to become active in the evolving national energy balancing and trading markets.

A number of business models were analysed and two models, an informational demand response system and an actuated demand response system, offer the best potential at the present time. However, moving forward, there will be scope to consider features for providing energy services and complementary technology assessment.
Table 6.1 highlights the deployment requirements for the informational and actuated demand response systems. Table 6.2 compares the two scenarios. The informational system is easier to install and cheaper than an actuated system but in the field trials there were issues with generating and maintaining interest. The actuated system is able to offer a firmer level of response but the technical jeopardy is higher.

Scenario	Simple Monitoring	Advanced Monitoring	Informational	Automatic Actuation
Informational Demand Response	X		X	
Actuated Demand Response		X	X	X

Table 6.1 – Deployment Features of the 2 suggested ORIGIN scenarios

Scenario	Deployment Difficulty	Cost	Effectiveness
Informational Demand Response	Easy	Medium	Medium
Actuated Demand Response	Medium / Hard	Medium / High	Excellent

Table 6.2 – ORIGIN Scenario Comparison

There are a number of market drivers and trends that will strengthen the market for an ORIGIN product, namely:

- Evolution in **customer behaviour** and expectations, with greater demand for reliable electricity and self-reliance, including becoming an energy producer, or “prosumer”
- **Policy** leading to increasing reliance upon renewable, intermittent resources and a shift to more decentralized energy resources
- Massive expected **energy efficiency investments** and structural changes related to codes and standards

- **Technological advancement** leading to alternative methods and designs for providing and integrating services to the grid that are provided by customers' responsive resources, including demand management, onsite generation and energy storage
- **Grid infrastructure issues** where exporting the electricity is not possible without significant upgrades to the distribution network

INNOVATION, DISSEMINATION AND IMPACT

1) Innovation

The main innovations resulting from ORIGIN which the beneficiaries of this award are actively exploiting include:

- **Automated Forecast Informed Vehicle Charging System (AVC)**: Leading on from the ORIGIN forecast informed vehicle charging system demonstrated in Tamera, a smart vehicle charging system was developed to TRL level 6 to increase use of local (or regional) renewable generation.
- **Residential Heating Control (RHC):** The ORIGIN informed demand forecasting is capable of controlling residential and commercial central heating systems and has been demonstrated in Findhorn to TRL 6/7.
- **Heat Pump Control (HPC):** The ORIGIN project developed a control system that optimised the use of Air Source Heat Pumps in conjunction with renewable generation in a community to TRL 6/7.
- **District Heating Optimisation (DHO):** The researchers developed district heating control strategies to optimise the preferential selection of energy sources to minimise imported energy to the community to TRL 6/7.
- **Thermal Storage Optimisation (TSO):** Origin developed an optimised strategy and algorithm for the control of thermal storage as an energy buffer for intermittent renewables to TRL 7.
- **Multi-Sensor Occupancy Detection Algorithm (ODA):** The project developed IP developed by HWU during a UK EPSRC project (APAtSCHE) to utilise the monitoring technology installed in Findhorn to estimate the occupancy state of the buildings involved.
- **Modifications to Products (MtP):** VPS (ISA) developed several enhancements to their ICT monitoring hardware to meet the monitoring needs of the project.
- **Accurate Localised Weather Forecasting (AWF):** ORIGIN produced a method of producing accurate localised weather forecasts to inform the demand forecasts at the communities.
- **Socially Inclusive Energy Tariffs (SET):** The project realised the need for socially progressive energy pricing to encourage and reward participation in demand response activities and make the benefits of renewable energy generation accessible to the general population.
- **User Interface (UI):** The project developed a web based Demand Response User Interface to engage the communities with information regarding community and personal energy use and to communicate demand response opportunities.

Their relationship to the ORIGIN architecture is shown in Figure IDI1.

Joint Venture Agreement (All partners) (All Innovations)

The consortium has been very active in seeking opportunities to exploit the ideas, technologies and results of the project. Being dominated by academic partners, this has led to many further research and development funding applications as described below, however the consortium recognised the need for a commercial entity capable of holding the intellectual property jointly generated by ORIGIN and enabling the partners to easily exploit it in an appropriate way following the conclusion of the research effort. The agreement recognises that IP produced by an individual beneficiary remains the property of that party but that IP produced by more than one beneficiary will be available for exploitation for all beneficiaries involved in its production subject to the terms of the Joint Venture Agreement.

Spin Out Companies (Partner HWU) (Innovation AWP, RHC)

Heriot-Watt University has created a University Spin-Out company to commercialise the weather forecasting IP developed during ORIGIN. The company is called AURAVENTI and HWU have made an application for a patent to protect the methodology (AWF) (US Patent Application Number 14/933211)

Heriot-Watt are also in the process of applying for a US Patent to protect the Intellectual Property developed surrounding the ODA innovation described above. It is the intention of HWU to invest this IP in a spin out company with the purpose of commercialising the multi sensor occupancy detection methodology. The draft patent application is being prepared for submission at the time of submission of this document.

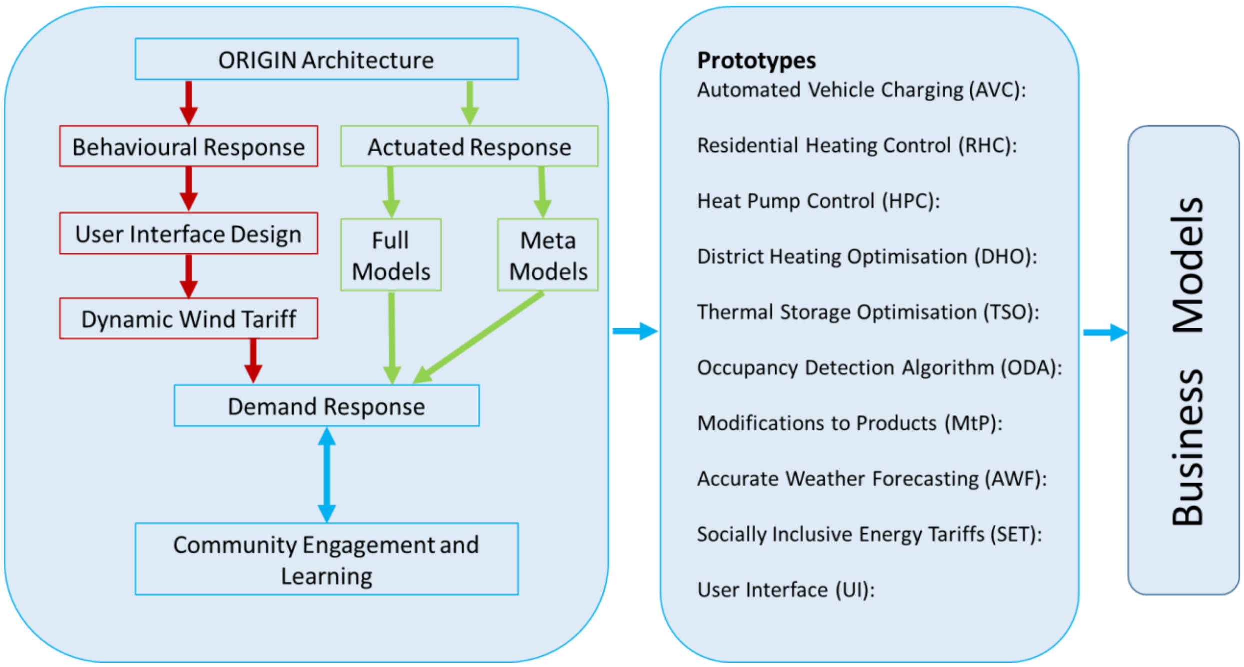


Figure IEI1: The ORIGIN project components and outcomes

Company Purchase (Partner VPS) (Innovation MtP)

Partly in order to create new products to exploit the ORIGIN research VPS, formerly part of Intelligent Sensing Anywhere (ISA), have purchased a UK based SME. This arrangement facilitates access to UK funding to continue the working relationship with HWU, FF and UoS. VPS has launched ISA's Cloogy® solution into the market providing households and small offices with energy analytics, monitoring and control features partly based on the innovations developed internally in support of the ORIGIN project.

New Product Development (Partner VPS) (Innovation MtP)

During the project VPS developed new features for its existing products to enable the project to progress and to establish new business opportunities. These innovations are listed below.

iPoint TH: A new version of iPoint for measuring temperature and humidity in indoor environments, suitable for being used in the Cloogy solution. This enabled the possibility to extend the VPS domestic solution to measure environmental parameters.

iPointCO2: A new version of iPoint for measuring CO2 levels in indoor environments, suitable for being used in the Cloogy solution. This enabled the possibility to extend the VPS domestic solution to measure additional environment parameters.

RTU Tri-Temp: New equipment to measure temperatures in multiple points of appliances/objects. This now enables the Cloogy solution to collect thermal device data for domestic energy management.

M-Bus gateway: New equipment to interface with M-Bus based devices, such as Heat-meters, water meters or others. This equipment enables the Cloogy solution to collect a broader quantity of measurement types from any M-Bus based device available on the market.

Home automation Cloogy: Re-development of the Cloogy solution having the main objective of replacing the proprietary Zigbee protocol used in Cloogy with the standard Zigbee Home Automation protocol. This enables the Cloogy solution to interface with other non-Cloogy zigbee devices, such as third party power-plugs (used to reach different markets using distinct plug formats), energy meters, thermostats, smoke sensors, door sensors, light dimmers and others. This implementation represents a huge improvement on the Cloogy solution, making it suitable not only for the energy market but also for security and other domestic application scenarios. The standard Cloogy devices (transmitter and power-plugs) were also migrated to the Zigbee Home Automation protocol, ensuring their compatibility to the new version of the Cloogy.
Improvement of the Data Server: Improvement of the Data Server have made it capable of integrating data from external devices such as weather stations.
Data Server Interface: Improvement of the Data Server interfaces to make it possible for external systems to retrieve data collected by the Cloogy solution.

Further Funding and Commercialisation (Partners HWU, UoS, FISE, ISA, ITI, FF) (All Innovations)

The project consortium has made multiple applications for further funding towards commercialisation of the ORIGIN concept. This includes but is not limited to the following applications.

VITAL Energy (Partners HWU, FISE, ITI) (Innovations RHC, SET, DHO, AWF, UI)

In June 2015 several of the partners form ORIGIN made a new application for funding to Horizon2020 with a new set of beneficiaries designed to provide the technical and commercial expertise to take ORIGIN towards a commercially viable option. The application was made to the call H2020-EE-2015-2-RIA as an Innovation action under proposal number 696054. Unfortunately the call was highly competitive and VITAL Energy was not selected for funding, however the partners intend to resubmit the project to an appropriate H2020 call in 2016 having considered the feedback form the review team.

An overarching theme of the project would be to widen access to the financial benefits of renewable electricity generation to include communities that are currently excluded from ownership of renewable resources through geographic or financial constraints. It will do this by combining the demand side management methodology developed and demonstrated within the EU funded FP7 ORIGIN project with novel energy trading business models to achieve economic rewards for both automated demand side management in the participating buildings and participatory demand management through well informed energy lifestyle decisions.

The project would effectively combine the ORIGIN energy demand management system that has been demonstrated in the communities with business models that enable it to be transferred into the energy retail sector. The ability to respond to low carbon energy availability signals will increase the useful uptake of locally and nationally generated renewable energy and demonstrate the energy and carbon savings that can be achieved at multiple building level by the intelligent orchestration of energy demand to better meet intermittent supply patterns.

VITAL Energy intended to bring together the ORIGIN concept with progressive energy retailers Our Power and SOM Energia to create a commercial ORIGIN system that provided social housing clients access to the benefits of demand response and energy trading.

UrbanLink (Partners HWU) (Innovations SET, AWF, TSO, ODA)
Heriot-Watt University have successfully obtained phase one funding for a "Local Energy Challenge Fund" project called UrbanLink in conjunction with Changeworks Ltd., Glasgow Housing Association and Our Power Ltd. The LECF is funded by the Scottish Government through Local Energy Scotland.
http://www.localenergyscotland.org/funding-resources/funding/local-energy-challenge-fund/2015-phase-one-projects/urbanlink/
Urban Link's vision is to widen access to the benefits of a local low carbon energy economy to urban communities through deployment of the ORIGIN forecasting techniques to socially responsible demand response.

The project will engage urban communities of approximately 1000 householders in demand management by installing ORIGIN technology to enable direct actuation of distributed energy storage in the community.
The advanced weather forecasting techniques developed by Heriot-Watt will be used to predict renewable generation at a national, regional and local scale and energy demand within the community. This will then be used to predict future periods of renewable generation availability and opportunities for increased use of renewable energy within the community. Moving demand into these periods will reduce peak load and provide flexibility to reduce electricity curtailment and lessen the negative impact that wind intermittency and forecast errors have on the efficiency of non-renewable generation. To enable a significant contribution towards demand side management from direct participation of customers it is imperative that the community are individually well informed of the availability and price of electricity. Heriot-Watt will adapt the user interface developed by the ORIGIN project to provide renewable energy forecasts based on accurate, highly localised weather forecasts.
ORIGIN has demonstrated that demand side management can play a role in increasing access of communities to renewable generation and the associated financial benefits. UrbanLink will develop a novel business model that reduces the price of electricity for the participants during periods of renewable generation availability. It will demonstrate that the ORIGIN approach is readily scalable and can be adapted to engage domestic and commercial customers in other locations.

SCORCHSys "Smart Control of Residential Cooling and Heating Systems" (Partners HWU, UoS) (Innovations SET, AWF, TSO, ODA)
The aim of SCORCHSys is to enable radically improved control of electrical heating and cooling systems in UK dwellings, based on fundamental advances in occupancy analysis and state of the art supply/demand forecasting provided by the ORIGIN project. Heating and cooling control system outcomes will be optimised from arbitrary perspectives, ranging from individual household energy affordability through to district-level electricity network management. New electricity retailing approaches will be investigated to explore how these economic benefits can be democratised and used to incentivise all stakeholders. The unique feature of this project is its scope to combine relevant forecasting methodologies developed during ORIGIN (e.g. household thermal demand, dwelling occupancy and network constraints) with the analysis of evolving electricity markets to deliver control approaches that are relevant to low carbon energy networks. SCORCHSys will address the need to reconcile demand management with affordable energy pricing at a community and regional scale. The project includes an industrial advisory panel comprised of research partners and industrial partners including manufacturers of heating control systems, progressive energy retailers and manufacturers of residential energy storage heaters.

This project has sought funding from the UK's Research Council and initial review comments have been very positive. It is expected that the decision on funding will be made in December 2015.

FITS-LCD: Fabric Integrated Thermal Storage for Low-Carbon Dwellings (Partners UoS, ICL, Bath, GSA)

This project has been successful in winning funding from the UK EPSRC and is now at contract negotiation stage. The aim is a re-envisaging of domestic thermal storage for heterogeneous low carbon energy sources and active energy network participation. This project seeks to generate the technical and economic concepts, undertake prototype technical demonstrations, develop software models and assess user acceptability, for the effective deployment of fabric-integrated thermal storage in dwellings and communities within the context of wider low-carbon energy networks. Work Package C 'Measurement and Control' led by UoS will build on work done in ORIGIN on the thermal model based control algorithms for hybrid renewable systems. There will be three core activities. (1) Measurement approaches for charge estimation in integrated storage and multiphase materials. (2) Developing balance of plant control algorithms for the orchestration of local and low carbon heat sources. Finally, (3) the development of algorithms governing participation in active energy networks and managing conflicts with local end-user requirements.

FinCARES (Partners HWU, FF) (Innovations AWF, TSO, ODA)

The Findhorn Foundation College and Heriot-Watt have applied for CARES funding to continue the ORIGIN demonstration on site in Findhorn. CARES is a Scottish Enterprise funded programme designed to promote community renewable energy projects. This project will seek to extend the ORIGIN automated demand response system to deliver increased "activation" of demand led controls of thermal energy loads and demonstrate its commercial potential. The outcome will result in loads being automatically shifted to maximise the use of existing biomass, wind and solar renewable energy at a greater scale and time frame than was achieved during ORIGIN and deliver a robust, commercially viable community energy management system. Its functionality will include the ORIGIN communication systems, directly actuating heating loads, including optimised control of biomass district heating systems. Initially the ORIGIN activation pilot will be assessed and potential applications under this grant application mapped. Additional self-learning activation algorithms will be written and initiated by Heriot Watt University. The purpose is to extend the computational system involving web-connected ICT ORIGIN algorithms to activate demand led controls. Activation of space heating and hot water supplies will be applied to a minimum of 29 buildings within the Park site of the Findhorn Foundation Community, involving heating from electrical heating systems, heat pumps and two biomass district heating network sources (WP6). The ORIGIN system will be maintained and further developed during this project. This application was submitted in October 2015 and the partners expect to hear the result in January 2016.

Construction Scotland Innovation Centre (CSIC) is interested in continuing the activation work, potentially initially funded by CARES. Work packages, using ORIGIN as the starting point, have been discussed with the funder CSIC. The nature of their support will depend upon the application for CARES funding mentioned above as the intention would be to run two complementary projects. FF envisages an application for total funding of £200,000. The applicant will be FF with HWU, UoS and Auraventi.

Energy Catalyst (Partners VPS, FF, HWU) (Innovations AVC, RHC, ODA, MtP and AWP)

Virtual Power Solutions (VPS) is the SME applicant for this application's consortium, which includes Heriot Watt University, Auraventi (the HWU/ORIGIN Spin-Out company mentioned above) and Findhorn Foundation College (FFC). This project's primary objective is the development and distribution planning of a "product" that applies the ORIGIN energy management technology to domestic energy installations. The OSD, which is the name used for the "product", combines occupancy sensing technology (ODA) with other components of the ORIGIN system to create an automated occupancy and demand informed heating control system. The research intends to extend the functionality of the HWU OSD to allow it to interact with programmable thermostats to optimise control of domestic sector heating systems, saving energy, CO_2 emissions and fuel bills as a consequence. This application was made in November 2015 and the outcome is expected in January 2016.

Blackwood Grey Fleet to Green Fleet LECF (Partner HWU) (Innovation AVC, AWP)

The Scottish Government has funded 23 stage one Low Energy Challenge Fund projects in 2015 one of which is “UrbanLink” as described above. Many of these projects involve community energy innovation and the publicity surrounding ORIGIN has led to HWU being asked to join two other of these projects to provide demand response capability for the projects. The “Blackwood grey fleet to green fleet” intends to store PV energy in a new home battery arrangement, which will subsequently be used to charge electric vehicles and also provide an Uninterruptible Power Supply (UPS) backup to Blackwood Housing’s new Telecare/ Smartcare digital platform for care homes / sheltered housing. This project will enable Blackwood Housing to become self- sufficient for transport power and use up to 100% of its own solar derived PV energy. The project hopes to use ORIGIN demand and supply forecasting to optimise the PV/Battery/Vehicle charging system.

Fintry LECF (Partner HWU) (Innovation AVC, AWP)

The Fintry Development Trust Smart Meter Commercialisation project will install electric heating or heat pumps in around 144 oil and LPG burning properties in Fintry to increase the use of anaerobic digester generated electricity and will match local supply and demand through smart metering and settlement systems to demonstrate that power from the AD plant was used concurrently. HWU and UoS have been invited to participate in stage 2 of this project with the intention of using the ORIGIN forecasting technology to optimise the energy system orchestration.

EClue (HWU, ISA, ITI) (Innovation AWP, UI, MtP)

During the ORIGIN project the project coordinator was asked to join two other H2020 proposals as a partner so that the ORIGIN results would be available to the proposals. One of these projects was called eCLUE – Personal Energy Consumption Monitoring and Advising to Support and it was submitted to call EE 11- 2014 – New ICT-based solutions for energy efficiency. The project focused on the change of behaviour of citizen’s based on information provide in places of work and public spaces such as museums and concert halls. The ORIGIN energy auditing methodology and user interface would have been adapted for use by eCLUE. Unfortunately this project was not funded.

North East District Heating Schemes (UoS, HWU, ISA and FFC) (Innovation DHO, TSO, AWP, MtP)

The University of Strathclyde, Heriot-Watt University and the Findhorn Community applied for funding to the Local Energy Challenge Fund in the UK to adapt the ORIGIN control ICT system and optimisation algorithms to improve control of district heating systems in the North East of Scotland. The application was made to the same source that has funded stage one of UrbanLink. The vision of this project is the supply of renewable, innovative, low carbon, low cost, sustainable and scalable district heating to 1,000 people in Northeast Scotland. This will be delivered through the installation of local district heating biomass systems, enhanced by solar thermal in multiple sites and optimised by the ICT smart energy management system developed during the FP7 funded ORIGIN project. The properties to be heated are part of a large housing association and on the campus of an educational charity. Local experience is that 85% of energy for buildings is used in space heating and hot water, making the opportunity and potential to install green infrastructure highly beneficial. The project will demonstrate the potential of the ORIGIN optimisation and ICT technology to control complex and diverse heating systems at community and city scale. The initial proposal was not selected for funding but the project team intends to resubmit it to other funding calls at a National and EU level.

2) Dissemination

The dissemination of the ORIGIN project research results has been ongoing since the inception of the project. It has taken many forms varying from public lectures to press releases and academic publications. The details of each of the activities undertaken are listed elsewhere in this report but some of the highlights are described in detail below.

Invited Lecture at the Scottish Parliament

In March 2015, the ORIGIN Project Coordinator was invited by MSP Joan McAlpine to give a presentation on ORIGIN and demand side management. Dr Owens highlighted the results of the project to date and made the case for energy storage to alleviate intermittent generation at a national and international scale. The presentation was well received and lead directly to Dr Owens being invited to appear as an expert witness to the Scottish Parliament. It also led to ongoing discussions with the Scottish Television regarding the possibility of providing a daily "renewables forecast" as part of the national evening weather forecast.

Expert Witness at Scottish Parliament

On May 20th 2015, Dr Edward Owens was invited as an expert witness to the Scottish Parliament's Committee for Economy, Energy and Tourism. The event was chaired by Murdo Fraser MSP and 'Eddie' was part of a round table discussion between the invited experts and MSPs.

Talking on the subject of "energy security" in Scotland Dr Owens focused on the problems associated with replacing thermal generation plant with intermittent generation sources, mostly in the form of onshore wind. He told the Committee that a reliance on importing fossil and nuclear energy may have a very positive effect upon Scotland's headline greenhouse gas emissions, but in reality we will simply be exporting those emissions to England.

Dr Owens referred directly to the ORIGIN project and pointed out that high penetration of intermittent renewables into the grid generation mix has created an urgent need to invest in large scale or distributed energy storage systems and to reconsider the traditional approach to retailing electricity.

IEA ECES Annex 31: Energy Storage with Energy Efficient Buildings and Districts: Optimization and Automation

The ORIGIN project has been identified as an example project by this Annex and invited presentations have been delivered by Dr Tuohy at Annex meetings in Ljubljana (Slovenia) December 2013, Milan Oct 2014, and Turin Jun 2015. Dr Tuohy has been selected as leader of Task A 'Modelling' of the Annex.

Lectures and Presentation

Throughout the project the partners have taken multiple opportunities to address different audiences concerning ORIGIN and its aims and objectives, results associated technologies. Some of the highlights include:

November 2013: Dr Owens gave a presentation to Community Energy Scotland's annual conference which was attended by over 300 delegates comprised of "energy aware" communities, local authorities, energy companies and other stakeholders in community scale energy projects. The ORIGIN project was well received and the public engagement resulted in the team developing links with several possible future collaborators including Energy Action Scotland and Highland Council who became supporters of later applications for follow on funding to continue the ORIGIN research towards new opportunities and possible commercial viability.

December 2014: Professor Corne presented an academic paper called "Accurate Localized Short Term Weather Prediction for Renewables Planning" at the IEEE Symposium Series on Computational Intelligence 2014. This was published in the conference proceedings by IEEE. The results of this publication were used to inform a US patent application number 14/933211 filed in November 2015 and encouraged Heriot-Watt University to form Auraventi, a Spin-Out company intended to exploit the accurate local weather forecasts developed by Heriot-Watt during the project.

March 2015: A presentation on the ORIGIN project was delivered Industrial Power Association (IPA) Scottish Conference: "Is the Energy Future Secure and Balanced?" which resulted in engagement with Sgurr Energy, a worldwide energy consultancy.

April 2015 : Dr Tuohy gave an invited presentation on ORIGIN project at the Seoul Governments 'Energy Dream Centre'

Dr Joel Chaney undertook "conversations" about Origin at the Edinburgh International Science Festival in 2014 following on from setting up an exhibition stall specifically about ORIGIN at Dynamic Earth, Edinburgh in 2014. These public engagements helped raise awareness of ORIGIN and demand management amongst the general public.

Press Releases on ORIGIN were generated throughout the project with the intention of maximising exposure of the research activity to a wide variety of audiences. These press releases were coordinated by a professional media relations company Pagoda PR. The press releases generated significant media attention which included a live interview on BBC Radio Scotland "Newsdrive" programme by Dr Stuart Galloway of University of Strathclyde. In addition Dr Owens appeared on a BBC "Headlines" weekend radio show to speak about ORIGIN and its progress. Written press articles also include articles in The Times published in London, La Stampa in Italy and El Confidencial in Spain.

Heriot-Watt University produced a research video to highlight the ORIGIN project and its cross disciplinary partners from the School of Energy, Geoscience, Infrastructure and Society and the School of Mathematical and Computer Sciences. The video can be viewed on YouTube at https://www.youtube.com/watch?v=HTWqP7NlBlU&feature=youtu.be

Project Conferences

During the final year of the project the consortium organised two conferences. These were run in Findhorn and in Turin and served different audiences.

Findhorn Conference:

In June 2015 the Findhorn Community hosted ORIGIN's Harnessing Community Energies conference This conference attracted 70delegates from more than 10 countries. 6 presentations were given from project participants and other researchers and stakeholders and open discussions were held on the future of micro-grids, the low carbon transition journey and supporting and encouraging energy behaviour change. Shortly after this conference in July 2015, Findhorn also hosted the international Global Eco-Village Network (GEN) annual conference and findings from the ORIGIN conference were highlighted. The Global Eco-Village Network is the world's largest network of sustainable communities and corresponds to the one of the main target markets for the Orchestration of Renewable Integrated Generation in Neighbourhoods.

One potential spin out from this event is the possibility of installing an ORIGIN system in Auroville, a Findhorn sister Ecovillage in Tamil Nadu in India (www.auroville.org). Auroville generates more electrical energy than they use through wind and solar PV and ORIGIN is a natural fit with Auroville's private wire network. Representatives from HWU and FFC have been invited to visit Auroville in March 2016 to pursue this opportunity. Auroville advises the Indian Federal Government and the Government of Tamil Nadu State on renewable energy. Establishing ORIGIN in Auroville would provide an excellent demonstration of the technology in India.

Turin Conference

In September 2015 the ORIGIN team ran a technical conference to disseminate the main technical results of the project. This was primarily an opportunity for the project researchers to present their work in a semi-formal environment but also presented ongoing opportunities to disseminate the project results to other researchers in the field of energy management. The event was hosted by the Politechnico di Torino (Polito) in Turin. A keynote address on the subject "Energy Union revolution'" was presented by Francesco Profumo who was previously the Italian Minister of Education and is now the chairman of IREN. The conference presented seven papers based on ORIGIN research and six papers on other Energy Optimisation related projects. Five of these papers presented research from 5 other European funded energy projects – RESILIENT, EPIC-HUB, EINSTEIN, Empowering and TRIBE. All of the external papers are at the time of writing being offered the opportunity for publication in a special edition of the International journal of Sustainable Energy Planning and Management. All papers were reviewed by the editorial board comprising of senior members of the research team to ensure appropriate standards but will be subject to the standard academic scrutiny required for publication in an academic journal. The publication effort continues beyond the end of the project.

Academic Publications

The detailed list of academic publications produced and in production during ORIGIN is presented elsewhere in this report. In summary the research team has published or have submitted or are submitting around twenty academic journal and conference publications. Journals chosen and conferences attended were selected based on relevance to the particular result being published. For instance Dr Owens presented a conference publication "Autarkic Energy Systems: Balancing Supply And Demand with Energy Storage and Controls in Local Energy Micro-grids" at the Asia-Pacific Solar Energy Research Conference at the University of New South Wales in December 2014 to highlight the opportunities for demand management of PV and Solar hot water in communities. Professor David Corne published "Accurate Localized Short Term Weather Prediction for Renewables Planning" at the IEEE Symposium Series on Computational Intelligence 2014 to highlight the computational approach being taken towards weather forecasting by the ORIGIN project researchers.

3) Impact

At the beginning of ORIGIN it was anticipated that the Impact of the project would be summarised by:

a) The dissemination of the result of the project to inspire gradual rollout of the demand management to other communities in Europe and beyond catalysing both the supply and demand side of energy systems for the emerging market for smart energy orchestration systems. This would then fuel a cascade of new communities adopting similar approaches especially through the Global Eco-Village Network (GEN). It was further expected that in due course various aspects of ORIGIN would expand to broader application such as within business and industry and at larger scales than neighbourhood.

The project partners have disseminated the results of the project both locally, nationally and internationally. One excellent opportunity was the presentation given to the Global Ecovillage Conference, one of the target audiences identified at the start of the project. This has directly led to an invitation for the Project Coordinator to travel to a large eco-village member of GEN to examine the possibility of installing an ORIGIN demand management system in India. GEN connects more than 10,000 villages, urban neighbourhoods and intentional communities in more than 100 countries worldwide and extension to a second large community would potentially crate a critical mass of communities wishing to install ORIGIN technology. Also both Damanhur (as part of Ecovillage Design Education (EDE) course) and Tamera, both Global Ecovillage Network partners, hosted ORIGIN workshops thus further heightening awareness of ORIGIN within the Global Ecovillage movement.

However if ORIGIN is to maximise its impact upon society it must be disseminated into the general population. The SCORCHSYS and URBANLink projects (described above) are seeking funding from local sources in the UK and will provide an excellent opportunity to achieve this through the combination of ORIGIN demand management with socially responsible energy retailing. Both of these projects have recruited progressive energy retailers and owners of large numbers of social housing units. The impact in the UK, and across Europe is apparent if the system can be shown to be financially self-sustaining through progressive energy trading linked to ORIGIN demand response.

ORIGIN demand response systems have the potential to make a significant contribution to the optimisation of electric vehicle infrastructure through provision of demand response to the energy network and intelligent use of the storage energy potential of electric vehicle batteries. The Blackwood Grey Fleet to Green Fleet project will provide an excellent opportunity to demonstrate the application of an ORIGIN system to electric vehicle charging. The opportunities for successful deployment in a demand response system orchestrated to match intermittent generation through battery storage are many. This project will build on the limited electric vehicle charging system installed in Tamera during the project.

b) The summary short term impacts were summarised as being a significant reduction of consumption of imported energy to the communities and associated GHG emissions savings achieved through ICT demonstrated at both an individual and neighbourhood scale. It was also expected that ORIGIN would contribute to the opening of a market for novel ICT based customised energy demand management solutions with the objective functions of increasing the uptake of renewable generation, reducing the use of fossil fuel generated electricity thus achieving significant emission reductions.

Deliverable 5.7 provides details of the imported energy and carbon savings achieved at each of the Validation Communities during ORIGIN. However it is anticipated that these savings will be increased if the consortium are successful in their multiple applications for further funding from other sources at a local level and perhaps via H2020 calls in the coming months and years.

The Energy Catalyst project seeks to extend the advanced occupancy detection techniques demonstrated at Findhorn during ORIGIN towards commercialisation. It proposes a research and development project in collaboration with the Findhorn Community and ISA's newly acquired UK based company to develop a commercial prototype. The device will enable real time occupancy detection and machine learning methods of determining occupancy patterns in buildings which can then be incorporated into the ORIGIN system. The ORIGIN Infrastructure will be utilised to run a series of field trials to demonstrate the occupancy informed demand response control of up to 30 energy installations in the Findhorn Community. The immediate aim will be to reduce imported fossil fuel energy and increase uptake of community generated renewable energy, however it will also demonstrate the financial viability of co-ordinate demand response.

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