Tiree Energy Pulse: Exploring Renewable Energy Forecasts on the Edge of the Grid

Will Simm[1], Maria Angela Ferrario[2], Adrian Friday[1],Peter Newman[1], Stephen Forshaw[3], Mike Hazas[1] and Alan Dix[4]
[1]School of Computing and Communications, [2]Management School, [3]LICA, Lancaster University, UK
[4]Tiree Tech Wave, Tiree, UK and University of Birmingham, UK
{w.simm, m.ferrario, a.friday, p.newman, s.forshaw, m.hazas}@lancaster.ac.uk, alan@hcibook.com

ABSTRACT
In many parts of the world, the electricity supply industry makes the task of dealing with unpredictable spikes and dips in production and demand invisible to consumers, maintaining a seemingly unlimited supply. A future increase in reliance on time-variable renewable sources of electricity may lead to greater fluctuations in supply. We engaged remote islanders as equal partners in a research project that investigated through technology-mediated enquiry the topic of synchronising energy consumption with supply, and together built a prototype renewable energy forecast display. A number of participants described a change in their practices, saving high energy tasks for times when local renewable energy was expected to be available, despite having no financial incentive to do so. The main contributions of this paper are in: 1) the results of co-development sessions exploring systems supporting synchronising consumption with supply and 2) the findings arising from the deployment of the prototype.

Author Keywords
Social innovation; Sustainability; Energy; Electricity; Forecast; Renewable Energy

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
In modern times we are used to an electricity supply system which allows us as consumers access to as much energy as we want, any time we want it for relatively low cost. Much of this electricity is sourced from burning a carbon rich diet of coal, oil and gas which has fuelled industrial development and economies. The future of this energy supply is looking rather less reliable. Borrowing from M. King Hubbert's peak theory [4], peak gas in UK was reached in the year 2000[1]. Much of UK's nuclear capacity is reaching end of life over the next decade, requiring renewal [25]. Diminishing reserves of fossil fuels, and thus vulnerability to volatile costs, and a need to meet stringent targets to de-carbonise the energy supply may mean increasing reliance on renewable energy in the coming decades. Unless storage of energy becomes viable to avoid blackouts becoming normality [23] we will need to synchronise our consumption with the availability of this resource.

Figure 1. Tiree Energy Pulse located device.

In this work researchers have spent 250 person days living and working in this new energy context through fieldwork on an island at the edge of the electricity grid, with its own community-owned wind turbine. Through a series of technology mediated interactions, including interviews, field visits and workshops, we worked with various stakeholders to explore the design of new technologies to promote awareness of variable and intermittent supply. One branch of this work resulted in developing a display called 'Tiree Energy Pulse' (TEP, shown in Figure 1) designed for and with Tiree islanders that presents the *energy 'pulse'* of the island, integrating a local renewable energy production forecast with a local

CHI 2015, April 18–23, 2015, Seoul, Republic of Korea.

ACM 978-1-4503-3145-6/15/04 ...$15.00.
http://dx.doi.org/10.1145/2702123.2702285

[1]UK gas and electricity crisis looming:
`http://www.resilience.org/stories/2005-08-27/uk-gas-and-electricity-crisis-looming`

weather forecast. Over a period of five weeks researcher-developers worked with a group of community-developers who acted as the participant stakeholders in the development process. Since the community-developers were embedded in the process they took real ownership of the system they were contributing to. While we deployed and developed this display with no expectation of change, this paper presents our findings which detail the actions around intermittent renewable energy and practices in relation to the presence of the display in their homes.

Through this study we are observing the effect of giving people the information about local renewable energy availability. This may involve shifting the usual time of doing energy intensive tasks (laundry, running the dishwasher, cooking, heating etc.) to times when local renewable energy is available, or simply placing in mind an awareness of when renewable energy is available. In all except one household who had their own micro-generation, there was no financial incentive at all. In contrast to most prior studies the participants were not paid for participation nor for shifting their energy usage. Our intention was not to encourage them to lower demand, rather give them the tools to be able to synchronise with the cycles of naturally occurring renewable energy.

The key contributions of this paper are firstly A) developing a renewable energy forecast with domestic consumers which has been under-explored in HCI literature, and in particular with no financial incentive, secondly B) observations on this which have implications for how we might design such systems in the future.

Context

"Eco-forecasting" of the type we investigate presents expected future state to users. This gives opportunity for the person to make a change—to delay or reconfigure performances *before* they are carried out. This is in contrast to "eco-feedback", which allows people to see only their past—which cannot be changed, and may require significant interpretation of practices to apply to changes in the future.

Using less energy is accepted as appropriate to reduce environmental impact, however renewable energy also provides opportunity to raise (or shift) demand in times of plenty. Currently grid systems struggle to handle the peaks in supply from renewable energy: in 2014 in the UK alone, wind turbine operators were paid over £53 million to constrain output[2] at times of excess. Eco-forecasting provides the tools to plan, helping to maximise this opportunity.

Tiree Context

Tiree is a small island off the west coast of Scotland, with approximately 650 inhabitants spread thinly in farm crofts and small clusters of homes. Tiree is 'on the edge' of the UK's infrastructure, connected to the electricity grid by a fragile subsea cable and reliant on a subsidised ferry service and airport for transport and other supplies. This community on the edge provides an ideal environment to foster innovation that may be generalisable beyond the island. Ferrario et al. [8] explore the energy situation in Tiree more completely, but for context a summary is provided here.

Tiree has a community owned wind turbine, an Enercon E-44 rated at 910 kW known locally as 'Tilley'. Tiree Trust operate Tilley through a wholly owned subsidiary which sells electricity to the UK grid on a feed-in tariff, and the money is used to fund community projects. Along with private solar panels and wind turbines, renewable sources are capable of supplying ⅔ of island peak demand, although this energy is only available *on supply*—when the wind is blowing and the sun is shining, not typically aligning with peak demand. Excess energy is exported to the mainland grid, incurring associated transmission losses.

The exposed location means islanders suffer several power cuts from storm damage annually and recently the sub-sea cable to the mainland failed completely, requiring replacement. During periods of disconnection from the mainland grid, the island relies on a diesel fuelled power station to cover the approximately 1–1.5MW of nominal demand—and Tilley is braked to tickover at 50kW, as the island infrastructure cannot respond quickly to the variation in supply as the wind rises and falls. In many respects, the energy supply on Tiree is less secure, more intermittent, and contains a greater mix of renewable sources than the mainland.

Global Context

In 2009, the world relied on renewable sources for around 13.1% of its primary energy supply[3]. Renewable sources accounted for 19.5% of global electricity generation and 3% of global energy consumption for road transport in the same year. However with most renewable energy supplies comes a new challenge—how to balance the grid when renewable sources of energy are so time variant: wind power is only available when windy, solar energy when the sun is shining. Using energy when it is available helps mitigate this problem.

Our work has increasing relevance in the UK through problems with electricity supply due to ageing infrastructure and delayed plant replacement. Dynamic peak pricing already impacts large energy consumers in the UK, and although politically sensitive, consultations have been made with domestic consumers regarding demand side response [11]. Infrastructure that can support this is being rolled out in the form of smart metering by 2020[4]. In Australia time of use pricing is already used, with Strengers finding there is a strong social inclination to respond to problems in supply [21], here eco-forecasting may further support this. Presenting localised energy forecasts in locations that suffer rolling blackouts and brownouts, e.g. in parts of Asia[5] may help domestic consumers to plan and make best use of energy when it is available. Similar Eco-Forecasting designs to TEP might also prevail in western locations that, like Tiree, have a high concen-

[2]Renewable Energy Foundation: Balancing Mechanism Wind Farm Constraint Payments
`http://www.ref.org.uk/constraints/indextotals.php`

[3]IEA Statistics `http://www.iea.org/statistics/`

[4]Policy: Helping households to cut their energy bills
`https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills/supporting-pages/smart-meters`

[5]Electricity in Vietnam: A heavy load `http://econ.st/1rusUUo`

tration of wind or solar energy such as the Pacific Northwest of the USA and parts of Scandinavia.

RELATED WORK

There is much written about presenting consumers with the amount they are consuming, with smart metering, home energy displays and all manner of visualizations pitched to encourage people to change what they do, in ways that reduce energy demand. The success of these devices is apparently limited, with consumption changing little [22].

Eco-Feedback

The centralisation of generation, grid balancing mechanisms, market forces and tariff construction have hidden the complex and sometimes fragile energy production and distribution process from most people. Making energy and the degree of usage more visible and easily interpreted by consumers is a goal of eco-feedback. Pierce and Paulos [16] summarise the state of eco-feedback within the HCI literature and argue a need to move beyond visualizing consumption. The effectiveness of portraying consumption is limited, it is understood that that energy use is the result of supporting everyday practices (showering, laundering and keeping warm), which are mediated by social, cultural, technical and institutional dynamics, rather than as a series of rational informed choices [22]. Rather than consumption, our focus is the times of the day which renewable energy is expected to be available.

Yang et al. [27] studied the use of a learning thermostat in 19 households and distilled a set of design implications for Eco-Interaction systems. In the first few months of intervention, user interaction had a large impact as the system built a schedule. Long term, the device required less frequent interaction and user interest waned, reducing the effectiveness of the devices as the user schedule evolved. In their implications Yang et al. suggest that employing mixed initiative designs, providing actionable recommendations, and stimulating reassessment may be starting points for designing more effective eco-interactions in the future. In this veign, TEP is designed to invite reflection and augments the existing practice of weather forecasting.

Eco-Forecasting

Extending weather prediction to forecast the availability of renewable energy has also been a focus of prior work [14, 19]—and indeed is fundamental to energy markets for balancing supply against demand. While these forecasts are used extensively by energy markets and grid operators, they are rarely presented directly to domestic consumers. Where renewable energy forecasting has been used with consumers, these forecasts have frequently been combined with other factors to estimate the likely cost of energy to encourage demand shifting [2] or automate household tasks [13]. We frame our system in terms of energy availability, rather than in financial terms.

Costanza et al. [2] specifically examined laundry routines, and propose a smart grid approach with real-time pricing asking participants to book a time slot for their laundry. Price forecasts were derived from weather and demand forecasts, assuming renewable energy is cheaper and this price would change as forecasts were updated. The information was presented to the participant as a likely price, with the source of the energy masked by the algorithm. They found that consumers were prepared to shift their laundry with an associated financial incentive, however no comment was made about motivations to synchronize with local renewable energy.

Bourgeois et al. [1] studied the routines of households with their own solar micro-generation. These households effectively get free energy when the sun shines and have invested in the generation technology—so are significantly motivated to make best use of this energy. Charts of historical production and forecasts (derived from cloud-cover weather forecasts) for the coming days' production as a fraction of the maximum output were emailed to participants every three days as a mechanism to allow users to plan household tasks. A washing machine that automatically selects the optimal time (within a user selected period) to start based on forecast data was also deployed. TEP in contrast offers a live forecast display of community scale renewables, where there is no individual financial reward.

There are online sources that show the live state of the UK grid[6]. The energy mix from this data is presented to users by Earth Notes' "GB Grid Intensity"[7], where the data is presented as a traffic light system. They also give advice to consumers about the carbon content of energy at the current point in time, encouraging them to shift consumption to times of higher renewable availability.

Schrammel et al. [20] proposed an ambient display of future renewable energy availability in the form of a wearable watch design concept. This design augments a clock face with an overlay of the next 12/24 hours of renewable energy forecast, and live and historical household consumption. This design was created following a workshop with end users, but was sadly neither implemented nor trialled.

Shifting Demand

A key concern of the electricity grid is to balance supply of energy to meet demand. This demand levelling is a concern of the grid operators [12]. Through the drive to reduce carbon output to meet carbon targets, time varying renewable sources will in future make up more of the energy mix and increase the complexity of this problem.

Pierce and Paulos [17] found that by displaying the live state of local renewable energy in two households, people would be willing to shift laundry to times of plentiful supply. Participants also reconfigured some practices to make use of energy when it is available—such as celebratory meals. They did not include forecasting in their display—however one of their participants suggested this.

Scottish Hydro's *Total Heating Total Control* (THTC), uses remote controlled electric storage heaters to synchronise use

[6]UK Balancing Mechanism reporting
`http://www.bmreports.com`

[7]`http://www.earth.org.uk/_gridCarbonIntensityGB.html`

with available off peak electricity [7]. Dynamic peak pricing (DPP) in Australia combines punitively priced electricity at times of very high predicted load, together with a range of notifications (SMS, Phone, in-home-display, email) to temporarily reduce the use of electricity (mainly due to air conditioning) on particularly hot days [21].

For households with their own micro-generation, there is a financial motivation to shift demand to make best use of their generation and minimise the cost of buying grid energy. In a study of attitudes towards micro-generation, researchers presented data driven probes exploring how to get the best out of micro-generation [18], and found households questioning their consumption and shifting demand to times of peak generation, however they did not explore energy forecasts.

Community Engagement in Energy

How households engage and communicate around home practices and strategies for shifting consumption when compared with one another was described by Dillahunt et al.'s 'social-energy' study [6]. Although we did not encourage households to compare energy use, tools like TEP have the potential to enable households to come together and discuss strategies for shifting consumption in a similar manner. Dillahunt et al. [5] also focus specifically on energy-reliant practices in households that did not pay for their energy, thus removing financial incentive. Despite this, they found participants were motivated to save energy, citing protecting the environment and an aversion to waste as motivations.

On the Isle of Eigg in Scotland which is powered totally by off-grid community owned renewable sources, households are subject to a 5kW cap. Households are asked to voluntarily reduce their electricity demand when renewable sources are running low using a traffic light system in community areas [26]. Here they do not give forecasts of when energy is likely to be in abundance or forecast periods of low supply.

METHODS

This work was conducted as part of the *OnSupply project*, a nine-month (November 2014–July 2014), sub-project of the Catalyst! project [24]. OnSupply brought together in partnership a multidisciplinary team of academics, residents of Tiree, and community leaders Tiree Trust. The main goal of the OnSupply partnership was to investigate if and to what extent digital technology can help people synchronise to the dynamic nature of renewable energy sources.

We follow Speedplay [9], an interdisciplinary management approach for the rapid prototyping of digital tools with a social innovation remit. This paper concentrates on the Speedplay *Build Step*, where a prototype is built in collaboration with a core user group engaged as equal partners, through an agile process where we deliver working software from the outset and capture participant feedback on the system developed as build iterations progress. In contrast to traditional prototyping, here the build step integrates ongoing community engagement and domain understanding into the process.

Most prior studies of this type of domestic intervention [2, 3, 17] deliver a complete working technology designed by researchers to homes and then study the use of it. Speedplay ensures that our participants are an intrinsic part of the design of the technology from an early stage–they were involved in ideating, designing, building and evaluating features as the technology was iterated. A key aspect of this was that we were able to capture a wealth of information about the impact the technology was having in the home, and that participants take considerable ownership of the resulting prototype and its refinements.

Tiree Energy Pulse—Emergence

This work builds on our prior work [8, 10, 15] which explored opportunities for designing ICT to support synchronisation with renewable energy supply. This work comprised of series of workshops that took place as a 'technology mediated enquiry' over a period of 8 months, engaging community members on Tiree throughout. These workshops were used as a means of eliciting requirements for a future energy scenario which relies on renewable sources—and the results of these workshops directly informed the inception and design of the TEP system.

Through this work [8] it is suggested that the opportunities at a community level for synchronising everyday life with supply are *opportunistic exploitation*—having mechanisms that can take advantage of energy when it is in plentiful supply and cannot be electrically stored, and *collaborative load management* where the technologies that help the community to predict and plan for future availability. One of the major themes elicited through a game workshop and refined through physical prototyping [15] was *forecasting*—presenting the likely future availability of energy.

The initial ideas for TEP arose from a subsequent physical prototyping workshop, where a physical prototype was used as a provocation to inspire the participants into thinking about what may be possible in ambient displays in future. This prototype, called the 'Datarium' comprised a 3D printed bulb-like plant with leaves that move and change colour with the live and forecast state of renewable energy on the island. Two of the recurrent themes that emerged out of this were (i) a desire for more clear information on the live and forecast state of renewable energy than presented by Datarium, and (ii) participants likened the Datarium to a 'tamagotchi' digital creature, and liked the idea that it gave advice and required interaction and action to survive.

Tiree experiences amongst the highest persistent wind speeds in the UK as well as boasting one of the highest annual hours of sunlight in the UK. The weather on Tiree has a massive impact on daily life and routine on Tiree and because of this we decided to augment existing performances of checking the weather forecast with our renewable energy forecast. Our intention was to augment an existing practice with a mixed initiative design to increase engagement [27].

Tiree Energy Pulse—Description

The name 'Tiree Energy Pulse' represents an attempt to show the *energy pulse* of the island, natural energy overlaid with electrical energy generated directly from nature, to present an opportunity to synchronise with natural energy cycles. TEP

Participant	No. Calls	Attended Workshops	Discussion Group	Household Inhabitants	Heating / Hot Water	Electricity Tariff	Cooking	Dryer
Janet	2	Yes	Present	2	Oil	Conventional (RE supplier)	Bottled Gas	Yes & used
Tony	2	No	Present	4	Air source heat pump	Conventional	Bottled Gas	Broken
Sarah	2	Yes	Interviewed	1	Coal Fire & Electric	Economy 7 (TOU)	Electric	Once a year!
Linda	2	No	Not present	2	Electric, Multifuel / Solar	Own turbine with feed-in tariff	Electric	Not used
Trish	0	Yes	Not present	2	Electric / Solar Water	Conventional	Electric	None
David	1	No	Not present	2	Electric Storage & Multifuel Stove	Total Control	Electric / Multifuel	None
Margaret	2	Yes	Present	2	Electric Convection / Electric	Conventional	Electric	None
Natalie	1	No	Present	2	Wet Electric / Electric	Economy 7 (TOU)	Electric	None

Table 1. Participants to the study (names changed). All have and use a washing machine and all except Sarah have and use a dishwasher.

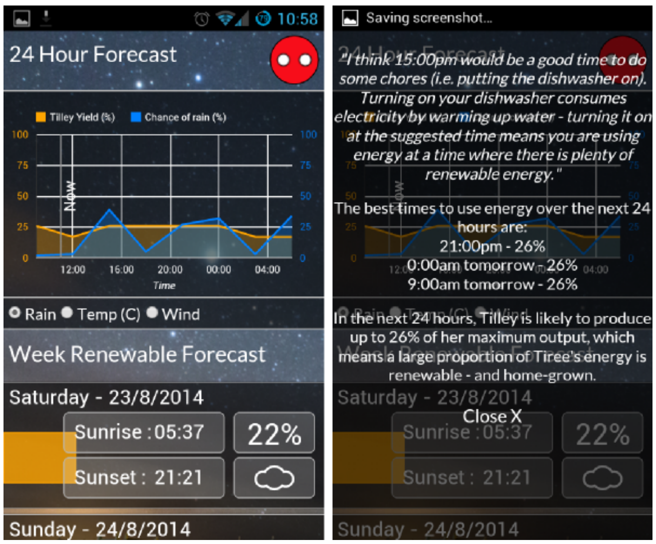

Figure 2. Tiree Energy Pulse Screenshot. Blinky is the red circle in the left screenshot and when clicked gives the advice shown on the right.

is a located display of a renewable energy forecast which was deployed to the homes of the participants as shown by Figure 1. The display shows a line chart showing the day ahead forecast of Tilley's output, overlaid with weather forecast data such as temperature and chance of rainfall. As the display is scrolled, it gives a week-ahead energy and weather forecast split by day. In the top-right is 'Blinky' (named by participants), who when pressed will give a text summary of the energy situation and give actionable suggestions to when might be a good time to do high energy and weather dependant tasks such as laundry. Since TEP was built as a flexible web app, TEP can be viewed on the supplied located display, or on a participant's own smartphone, tablet or computer.

The first version of TEP was built by the research team and the induction for participants provided the first round of feedback. As the five week development period progressed a number of features were refined and added as a direct result of participant feedback. A screen shot of the last version of TEP is shown by Figure 2, and the major features and the evolution of TEP are described below.

Day Ahead Energy Forecast
The primary display area was used to show a day-ahead forecast of the energy produced by Tilley. When the app is viewed with a landscape screen (as in the located device in Figure 1) this takes up the whole screen. To produce a forecast of Tilley's electricity generation, a weather forecast was obtained from the MET office DataPoint API[8] for Tiree airport. The wind speed forecasts from this were used to look up the corresponding turbine output from the manufacturer supplied datasheet[9]. The energy forecast was presented as a fraction of the peak output of Tilley, rather than electrical units which partipants did not find easy to interpret. Although the forecasts are presented as likely representations of future energy availability, any forecast has error to some degree [14]. In this study our focus is not the accuracy of the forecasts supplied, rather we observe the reaction to giving people this information that they did not have before—the forecast was presented as being as likely to be correct as a weather forecast.

Five day forecasts
The participant can scroll down to see a week ahead energy forecast. Since space is limited the five day forecast data was shown in a lower resolution (daily forecast rather than hourly). This also provided an alternative representation of similar data which the participants could comment on. The same algorithm was used as the day ahead forecast to give the week ahead energy forecast, again annotated with weather forecast data but here using conventional weather symbols.

Blinky
Blinky suggests the best time to do energy intensive tasks. Blinky emerged from the 'datarium' workshop described earlier where in discussion participants likened a physical representation of energy to a 'tamagotchi' that required regular interaction—Janet: "*I think its really cute (...) it would be good if it talked to you*" and Margaret: "*Maybe when lots of energy is being used, maybe its, you know, unhappy*".

Blinky is located in the top right of the display and the colour of Blinky's face represents the energy outlook for the next 24 hours—red for low turbine output changing through to green for high turbine output. This is calculated from an average of the next 24hrs forecast data, not a live figure. When selected, Blinky pops up a message suggesting the best times in the next twenty-four hours to do energy intensive tasks—so Blinky highlights the peaks in turbine output. Blinky also suggests the best time to do specific tasks—a period of high turbine output (to power washing machine), followed with

[8]Datapoint `http://www.metoffice.gov.uk/datapoint`
[9]Enercon Product Overview `http://www.enercon.de/p/downloads/ENERCON_PU_en.pdf`

low precipitation (for drying washing without using a dryer) will result in Blinky suggesting a good time to do laundry.

TEP Development and Participant Engagement

TEP was continuously developed over a period of five weeks with regular contact points with participants. The participants were drawn from the pool of full-time Tiree residents who had taken part in earlier activities and shown an interest in the process. An email was sent out and 8 participants (and hence 8 households) came forward to commit to the process and represented different demographics with people involved in roles such as community leadership, teachers, retirees, and remote tech industry workers. Table 1 lists the participants, along with the times they were contacted after the induction, household infrastructure used for common domestic tasks, and electricity tariff information. Note that names have been changed so participants remain anonymous. Although we did not pay our participants, Linda owns a domestic turbine and benefits from 'free' electricity when it is producing, so is the only participant with a financial incentive to synchronize tasks with renewable supply. Regarding selection bias, an environmentally aware mind-set is prevalent in inhabitants, perhaps arising through the exposed realities of island life, but we would not necessarily characterise all as being sustainably minded.

Deployment

A researcher visited Tiree 16–18 June 2014 to conduct inductions to TEP. Out of 8 participants 6 inductions were conducted face to face and 2 were done over the telephone.

TEP was deployed on an Android smartphone, with a stand designed to hold the phone horizontally, and left plugged in at a location of the participant's choice. The setup is shown by Figure 1 and a screenshot in Figure 2. The device was to be located in the home so mobile connectivity was not required.

TEP was pitched to participants as 'a device to give an at-a-glance view of the renewable energy situation right now and near forecast, with the aim of providing information to sync up with supply'. It was made clear that TEP was in an embryonic stage and it was a first prototype that is far from perfect or a final product. The development process was described to the participants—that they would be involved in proposing, defining and evaluating features through feedback telephone interviews in the coming weeks. Participants were given a participant information sheet and consent form, and the first follow up call was scheduled.

The TEP device was connected to the participant's WiFi for Internet access, and the unique participant ID recorded. The features of the app were described to the participant on the device, and the web app brought up on the participants own smartphone and other devices (tablets, laptops). The participant was given time to familiarise with TEP and notes were taken on their initial reaction to the presentation of information. The device was located in the participants household and a photo taken. A number of potential new features were discussed with the participant to inform future development.

A discussion followed, with the aim of discovering the the perceived high energy tasks in the home, how and when the decision was made to carry out those tasks. The participant's energy tariff (time of use, total control, standard) was recorded. We asked them what they knew about Tilley, and the energy mix on the island.

Phone Contact

Over the period of the study, each participant was called by telephone to capture feedback on the usage of TEP and development of features (again, see the table in Figure 1 for a summary of contact). The number of calls varied according to level of participant engagement and participant's availability. One participant contributed by email. Prompts for the telephone conversations included: number of uses and when it was used; for what purpose it was used; which devices were used to view TEP; location of device; clarity of information display and existing features; proposed new features; and finally a short brainstorm of future features was held.

Discussion Group

Before the discussion group, researchers planned a set of guiding questions centred on the *use, usefulness, usage* and *future vision* of TEP. These were used as prompts—the discussion was open to change direction; so the discussion was not limited and it ranged much wider. The usage traces for each participant present were displayed and participants asked to guess which was theirs to see if they used TEP as they thought. Unfortunately half of the participants could not make the discussion group, 4 of the 8 were present.

FINDINGS

Here we summarise the findings that emerged, drawn mainly from the discussion group but also from the consultations during the development period. We broadly split findings into categories, looking at the different uses of TEP, how it fit into the household ecosystem, changes in household practices and a review of the interface elements.

Uses of TEP

TEP combined a local energy forecast with a local weather forecast in one view. Some participants primarily used TEP for the energy forecast to help plan tasks- Natalie: "*I was basically using it as a way to estimate what was good to do, like lots of washing on today and whether was going to be windy enough to get it dry*", and some used it purely for the weather forecasts - Tony: "*I find it more useful as weather app*". When used for weather forecasts the energy forecast is implicit - Natalie: "*I think it was quite nice to have something where you go to check the weather in principle and then it makes you think, all right this is Tilleys production today*" so the participant gets the energy information as well, even if they did not specifically look for it or do not plan on doing anything with it. The weather overlay was well received so it remained for the duration of the study.

David, Sarah, Linda, Natalie and Tony all used TEP on supplied located Android devices positioned in their kitchens. Margaret used her own iPhone smartphone as a located device (left on her desk), whereas Trish preferred to use her own iPhone mobile smartphone, and Janet used her own (mobile) iPad tablet. The system was largely platform agnostic so a preference for alternative platforms was not a problem.

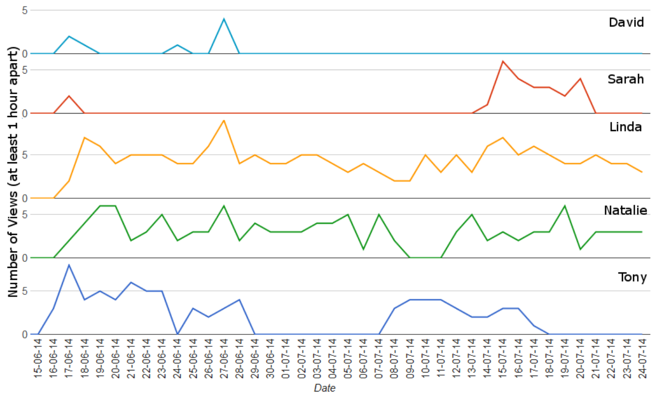

Figure 3. Usage traces for participants using located Android devices.

For those that used the Android device we supplied, we were able to track the number of views of the TEP forecast the participant's household made. Unfortunately we were not able to track the usage of iPhone and iPad devices. The usage traces for those that used the supplied Android devices are shown in Figure 3. Here a 'reloads' or views of TEP are only counted if they are at least 1 hour apart. Sarah was called away on a work trip for part of the study accounting for her early lack of use. David also took a holiday early in the study, was not available for telephone calls and perhaps lost interest in the study. What is especially interesting from the plots is that Tony indicated he did not use the located device much, however somebody else in his household did use the device fairly regularly. Over the short period of this study it was not really possible to say if the users got into a routine, however it is apparent that Linda, Natalie and Sarah (when she was in the country) did look at TEP a number of times every day.

TEP in the Household Energy Ecosystem

In the short period of the study, participants developed practices to maximise usage on days where local renewables were abundant. Their only motivation in this was to make better use of local renewable energy when it is available. Margaret: *"if it is a windy day, you know and Tilley is producing, you could justify that you could do the washing AND the tumble drying because Tilley is producing a lot!*" and "*when blinky goes green I think 'free run'—I can run the washing machine, now I can do the dishes*". Margaret prioritised her tasks—so at times of high local renewable energy production Margaret would do the low priority loads: "*I do the pet laundry because I always save that for the green. The pet laundry isn't as important as the human laundry, the dog's walking round without a clean bed is fine, but us walking round without clean clothes is another thing. So on green days I'm like 'strip the bed, strip the tables', do the dog's laundry and we can run the dishwasher all the time, we sort of see the green days as 'yeah go for it'*".

The two energy intensive tasks that were highlighted by the participants to be negotiable and acceptable to shift timing to some extent were laundry and using dishwashing machines—Margaret: "*I could run it today, or leave it and run it twice tomorrow when the wind is really up*". For Margaret, some of these 'negotiable' tasks were season-dependant: "*I think that would be something that I would be doing more in winter because in the summer I do not like leaving dirty plates because you get flies, but in the winter when you do not get the flies, I'd be more inclined to take wait and take advantage of energy supply from Tilley*".

Margaret reported gaining an 'energy instinct', TEP giving her the information required to correlate the 'feeling' of nature to the potential production: "*The feel of the wind versus how much energy is produced (. . .) so you are looking at it (TEP) and you know that Tilley is going to produce, e.g 10% and after a while you can go outside you can feel the wind level*". Sarah also reported this connection: "*When I use it, it makes me more aware, certainly of what I'm doing*".

Changes in Household Practice

Some participants felt motivated to make better use of local renewable energy—Margaret: "*well I feel a bit PROUD! Yes I am using Tilley's energy instead of a power station*". For Margaret and Natalie, checking TEP before doing laundry became routine. Natalie checked TEP each morning: "*I would think to go and check in the morning to be honest to see what was to happen and that dictated whether I was going to put the washing on or not*" and "*there was no real need to do it today and knowing if I did it another day meant a better use of local energy, that is a good reason to do it because I do not have any other factor for that decision making process*". Margaret delayed her washing: "*today is sunny BUT in two days is sunny AND windy, so we can wait for those days*". These are both households without children and they acknowledged this might make it harder- Margaret: "*I have laundry building up but because we do not have a family and we have got a week's worth of clothes we can wait two days.*".

For Tony, the pressures of family life (ever mounting piles of washing) meant it was not possible to integrate the energy mix into routines: "*if you've got a young family you tend to get things done as they pile up, [TEP] probably did not change our pattern of usage*", however there was an indication that it might be possible to change routine if the motivation was strong enough "*if you really really really try to get into a new routine it is possible, definitely possible, but I suppose it is convenience, you do what makes your life easier*".

Janet reported genuinely wanting to synchronise with renewable energy, and reported checking TEP every three days. However she didn't feel it meshed with the other drivers of the task: "*I am not very good with routines, so I wasn't going to do it (washing) at certain times, but when we were running out (of clothes)*". Janet felt a sense of 'guilt' that she did not manage to not change her irregular routines to synchronise, and did not understand why it did not happen: "*for somebody that is chaotic this could be actually a GOOD thing to have something that tells you when to do it, so I cannot quite work out why I didn't*".

Sarah felt she already 'minimised' her consumption, aiming to be as efficient as possible in her energy use. This was on her own timescales without consideration to synchronising with renewable energy. Despite reporting that TEP gave her more of a sense of the potential power generated in nature, in terms of taking action, Sarah highlighted there is a disconnect between the concepts of local energy generation and paying for it via a grid mix "*It doesn't affect what I do or switch on, because I'm not getting my energy from that source*".

Before TEP was introduced Linda already synchronised household tasks to the generation of her own turbine. Rather than use any digital display, she simply looks out of the window to see her turbine, and delays tasks such as washing and dishwashing until it is turning. In periods of low wind, she turns off her large electric 'Rayburn' stove as it is so well insulated it stays hot for long periods. However Linda's husband noted "*especially in the summer time when you don't have as much wind, you can only put off a job for so long*". The energy forecast provided by TEP did prove useful to them—Linda: "*it did change my planning, because I thought 'there's rain coming' go put the washer on, put the kettle on and have cup of tea*", and Linda's husband: "*if you need to do a job in the next couple of days, and you see that tomorrow is just as bad as today, you might as well do it today*".

TEP Interface

Throughout the study, we got feedback on TEP's interface and how it was used. participants felt they could interpret the information displayed by the chart easily and identify periods of high renewable energy availability - however there was some difficulty relating to the figures. Participants wanted to (or felt they should) understand what that meant in terms of familiar device consumption - Margaret: "*something like here we are producing enough to power 200 washing machines would make much more sense, although I like looking at the graph, I'm not sure I actually understand (in terms of) things that tie into everyday life*".

It was felt the 'located' rather than mobile nature of the TEP device supplied led to more use than it would viewing on a personal smartphone or browser—Natalie: "*yeah, I dont think I would have had look at it either if it was on my PC, it is just handy to have that thing there*" and Margaret: "*I could check it on my PC, go through my bookmarks, find the link, that little bit of extra time and effort that you do not feel like bothering, (...) when I see this (TEP device) I think 'oh yea! Lets check the weather'*".

Users liked that it is a tailored, local forecast that required no setting up—Natalie: "*so it is the fact that is local and it tells what is happening at my front door, rather than me having to try to find that information from a larger Internet space where there are lots of different things happening. This is what is happening here and it tells me immediately*".

Janet, Margaret and Sarah suggested push notifications could tell a user when a particular combination of weather and turbine output was expected, and that might prompt action- Margaret: "*you could set it when the weather/wind is such and such, ping me sort of thing*" and Janet would like to customize alerts: "*I would need a sound, but you could choose (the type of alert)*" and Sarah: "*I'm going to keep mulling it over to to motivate myself to use it more—I think push notifications would be useful*". Bourgeouis et al. [1] explored alerts of this type, and found their participants preferred to get advance notification of peak generation so they had time to plan and act.

Blinky

The reaction to Blinky's face was split—Margaret: "*just seeing the little thing it makes it more FUN! because you see this little thing and you feel a little bit guilty if you do not check on Blinky for a day*" vs. Natalie: "*it feels weird calling it Blinky*"; however, the role of Blinky in providing an 'at-a-glance' summary of the next few hours of production was well received by the participants—Natalie: "*It is quite useful to have that extra way of digesting the information*" and Margaret: "*when blinky goes green I think 'free run'*".

IMPLICATIONS

Here we discuss how our findings hold implications for the design of future domestic renewable energy forecasting systems, and for the sustainable HCI community.

Augmenting Existing Practice

TEP presented an energy forecast overlaid with weather forecast data, as a deliberate attempt to augment existing daily routines, and offer additional intrinsic value. The motivation for doing this was that much of life on Tiree is planned around the quickly changing weather using forecasts, and the forms of renewable energy currently available on Tiree (wind, solar) are intrinsically linked with the weather. Here bringing the two forecasts together helps plan a task such as laundry, which requires electricity to power the machine and dry weather to hang out washing. Both weather and energy forecast data are required to synchronise this task with renewable energy availability.

A number of our users liked to use TEP as a weather forecast—it presents data in an alternative way (wind speed line chart, temperature, chance of rain) to conventional weather forecasts (symbols), perhaps leading to novelty in the forecast and preference to existing services.

An implication for the future design of such systems is to consider how we might augment existing performances (like checking the weather), rather than requiring participants to adapt to completely new ones (like annotating an eco-feedback trace). For our case, we believe this resulted in increased engagement.

Building Understanding and Variation of Practices

We learnt there was a variety of energy intensive household activities and appliances. A number of our participants did not really understand the amount of energy consumed by different devices—for example we were asked if the computer used more, or less energy overall than the freezer. Every device has a power rating, however that is the maximum power consumed—easily understandable for a kettle, which always consumes that power when turned on but a little more difficult to interpret for a freezer which is not always running its compressor. Here we believe a wider understanding about relative consumption, and what constitutes an energy intensive action, is required before participants can be expected to change.

In the household there are tasks and sub-tasks with differing time sensitive priorities which may have negotiable timescales. For example one participant prioritised human laundry over her pet's laundry indicating that some tasks may be broken down further with some planning.

One of our participants hinted at seasonal variance in household practices. This has a big effect on synchronising with renewable energy—since the energy produced also varies seasonally. Clearly, more domestic heating is required in the winter, which aligns well with higher wind speeds in winter. But the feasibility of delays to other performances (such as Margaret considering delaying dishwashing, only in colder weather) should be considered.

Here the implications are to equip participants with the knowledge about the relative consumption of devices, and that prioritising tasks and seasonal variation should play a better part in negotiating practices.

Towards an 'Energy Awareness'

One of the interesting components of this study was to peel back the layers that hide energy production from consumption. In the same way that meat is bought neatly packaged on the supermarket shelf with little evidence of where it came from and the process it went through, the sources of energy are invisible to consumers.

In those that engaged the most with TEP, we found they had begun to develop an 'energy awareness'. Through observing the energy forecast a connection was made when later leaving the house and feeling the strength of the wind. Here a correlation between the 'feel' of the wind and the likely output of Tilley was made. Perhaps in the future this will mean to some extent TEP will become somewhat redundant, as that connection between weather and energy become implicit.

Transitioning Everyday Practice

This project was never presented to participants as a way to 'save money' or an attempt to 'persuade' them to change. The desire to make better use of local resources was already embedded to different extents in our participants before we came along. Given the energy forecast data, some participants apparently changed routines fairly easily, and they were able to describe these shifts.

Others did not change practice. For Tony, despite absorbing the forecast information, it was clearly much more difficult to change routine because of the number of tasks and the constraints of everyday life in a busy household. Janet had a strong desire to synchronise her tasks with Tilley's production, but she did not really plan her tasks in advance, for example doing laundry only when needed. She would arrive at the time laundry was needed and felt 'guilty' if TEP was indicated it was a 'bad time' but would have to do the laundry anyway. Here it is important to design interventions to avoid 'problematising' and blaming individuals.

Our participants reported that a financial incentive would contribute towards motivating them to synchronise with local renewable supply, and future tariff markets may exploit this to make better use of renewable energy. Our reason for not including a financial incentive here was to avoid abstraction away from the source of the energy—we wanted this study to be about synchronising with natural cycles of renewable energy supply (a long term societal benefit) rather than saving money (a short term personal benefit). That is not to say the two are incompatible.

The implication from this is that we found the motivation to make better use of resources already existed in our participants *without any financial incentive*, aligned with Dillahunt et al.'s finding of an 'aversion to waste' [5]. Not everybody was able to act on the information presented by TEP, and devices like the 'best use' washing machine by Bourgeouis et al. [1], can take their own action.

User Interface

In TEP we tried a number of interfaces, the detailed hourly line charts, the aggregate daily bar charts, the colouring of Blinky representing the coming hours, and the text based actionable recommendations provided by clicking on Blinky. We found different people preferred different representations, with layers of detail exposed through interaction. All users liked the tailored, local forecast which required no setting up or startup procedure. Participants found the figures TEP displayed were not easily related to house household consumption or specific devices. One interface we did not explore that we feel would warrant further exploration was that of push alerts, that would interrupt the user and notify periods of high or low production.

Our implication here is that interfaces need to be simple to operate with low user effort, yet present sufficient complexity of data to support decision making if that is the intention. An area for further investigation is how this type of forecast information in electrical units can be made relevant to and presented in a manner that is easily interpreted by domestic consumers.

CONCLUDING REMARKS

Tiree Energy Pulse explored the presentation of community wind turbine production in domestic homes on the wild edge of the UK infrastructure. The key contributions of this work are in: 1) the results of co-development sessions exploring systems supporting synchronising consumption with supply and 2) the findings arising from the deployment of the TEP prototype in the home.

Tiree has an unique energy situation that means consumers are somewhat disconnected from community energy production by the operation of energy markets in the UK. But the island has great potential to be an exemplar of practice which is more closely tied to its supporting energies. Our engagement in this unique situation has given rise to a potentially much broader set of community-scale interventions that we wish to explore in future work.

ACKNOWLEDGEMENTS

We are grateful to the islanders of Tiree and Tiree Development Trust for their participation. We gratefully acknowledge our funders EPSRC via Citizens Transforming Society: Tools for Change (CaTalyST!) ref. #EP/I033017/1. Our thanks also to Yolande Strengers for helping us to consider the importance of our participants' existing weather forecasting routines in our thinking.

REFERENCES

1. Bourgeois, J., Van Der Linden, J., Kortuem, G., Price, B. A., and Rimmer, C. Conversations with my washing machine: an in-the-wild study of demand shifting with self-generated energy. In *Proc. UBICOMP*, ACM (2014), 459–470.
2. Costanza, E., Fischer, J. E., Colley, J. A., Rodden, T., Ramchurn, S. D., and Jennings, N. R. Doing the laundry with agents: a field trial of a future smart energy system in the home. In *Proc. CHI*, ACM (2014), 813–822.
3. Costanza, E., Ramchurn, S. D., and Jennings, N. R. Understanding domestic energy consumption through interactive visualisation: a field study. In *Proc. UBICOMP*, ACM (2012), 216–225.
4. Deffeyes., K. S. *Hubbert's peak: the impending world oil shortage*. Princeton Univ. Press, 2008.
5. Dillahunt, T., Mankoff, J., Paulos, E., and Fussell, S. It's not all about green: Energy use in low-income communities. In *Proc. UBICOMP*, ACM (2009), 255–264.
6. Dillahunt, T. R., and Mankoff, J. Understanding factors of successful engagement around energy consumption between and among households. In *Proc. CSCW*, ACM (2014), 1246–1257.
7. Edberg, O., and Naish, C. Energy Storage and Management Study. Tech. rep., AEA Technology PLC, October 2010.
8. Ferrario, M. A., Forshaw, S., Newman, P., Simm, W., Friday, A., and Dix, A. On the edge of supply: designing renewable energy supply into everyday life. In *ICT for Sustainability 2014 (ICT4S-14)*, Atlantis Press (2014).
9. Ferrario, M. A., Simm, W., Newman, P., Forshaw, S., and Whittle, J. Software engineering for'social good': integrating action research, participatory design, and agile development. In *Proc. ICSE*, ACM (2014), 520–523.
10. Forshaw, S., Newman, P., Ferrario, M. A., Simm, W., Friday, A., and Coulton, P. Stimulating a Dialogue on Renewable Energy Through Making. In *Proc. DIS*, ACM (2014).
11. Frontier Economics and Sustainability First. Demand side response in the domestic sector-a literature review of major trials. Tech. rep., Department of Energy & Climate Change, 2012.
12. Guy, S., and Marvin, S. Transforming urban infrastructure provision—the emerging logic of demand side management. *Policy Studies 17*, 2 (1996), 137–147.
13. Liu, X., Ivanescu, L., Kang, R., and Maier, M. Real-time household load priority scheduling algorithm based on prediction of renewable source availability. *Consumer Electronics, IEEE Trans. on 58*, 2 (2012), 318–326.
14. Morales, J. M., Conejo, A. J., Madsen, H., Pinson, P., and Zugno, M. Renewable energy sourcesmodeling and forecasting. In *Integrating Renewables in Electricity Markets*. Springer, 2014, 15–56.
15. Newman, P., Forshaw, S., Simm, W., Ferrario, M. A., Whittle, J., and Friday, A. Seeding the design process for future problems.
16. Pierce, J., and Paulos, E. Beyond energy monitors: interaction, energy, and emerging energy systems. In *Proc. CHI*, ACM (2012), 665–674.
17. Pierce, J., and Paulos, E. The local energy indicator: designing for wind and solar energy systems in the home. In *Proc. DIS*, ACM (2012), 631–634.
18. Price, B. A., van der Linden, J., Bourgeois, J., and Kortuem, G. When looking out of the window is not enough: Informing the design of in-home technologies for domestic energy microgeneration. In *ICT for Sustainability (ICT4S)*, ETH Zurich (February 2013), 73–80.
19. Roulston, M. S., Kaplan, D. T., Hardenberg, J., and Smith, L. A. Using medium-range weather forcasts to improve the value of wind energy production. *Renewable Energy 28*, 4 (2003), 585–602.
20. Schrammel, J., Gerdenitsch, C., Weiss, A., Kluckner, P. M., and Tscheligi, M. Fore-watch–the clock that tells you when to use: Persuading users to align their energy consumption with green power availability. In *Ambient Intelligence*. Springer, 2011, 157–166.
21. Strengers, Y. Air-conditioning Australian households: The impact of dynamic peak pricing. *Energy Policy 38*, 11 (2010), 7312–7322.
22. Strengers, Y. A. Designing eco-feedback systems for everyday life. In *Proc. CHI*, ACM (2011), 2135–2144.
23. Trentmann, F. Disruption is normal: blackouts, breakdowns and the elasticity of everyday life. In *Time, Consumption, and Everyday Life*, E. Shove, F. Trentmann, and R. Wilk, Eds. Oxford, UK: Berg, Oxford, 2009, 67–84.
24. Whittle, J., Ochu, E., Ferrario, M. A., Southern, J., and McNally, R. Beyond research in the wild: Citizen-led research as a model for innovation in the digital economy. In *Proc. Digital Futures* (2012).
25. World Nuclear Association. Nuclear Power in the United Kingdom, February 2014.
26. Yadoo, A., Gormally, A., and Cruickshank, H. Low-carbon off-grid electrification for rural areas in the united kingdom: Lessons from the developing world. *Energy Policy 39*, 10 (2011), 6400–6407. Sustainability of biofuels.
27. Yang, R., Newman, M. W., and Forlizzi, J. Making sustainability sustainable: Challenges in the design of eco-interaction technologies. In *Proc. CHI*, ACM (2014), 823–832.