Tilly and the Myth of Energy Independence

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Introduction

In this note, we tell the story of how we developed our understanding of the ways energy supply and demand are entangled in geography and infrastructure on the Isle of Tiree in Scotland. This was an understanding we developed through a series of design encounters on the island, in which we used 'research through design' (Gaver, 2012; Zimmerman et al., 2007; Frayling, 1993) methods, first to engage with the island and its inhabitants, and later to work through imaginary future interventions on the island as a way of exploring what we had learned and the issues we had uncovered.

Because our methodology is oriented towards the development of new design propositions, and works through a process of emergence and discovery rather than investigation of a priori hypotheses or research questions (see Gaver 2014), this presentation will take the form of a narrative rather than a traditional research report. While we finish with a discussion of the issues we believe our work surfaced, most of this account will involve retelling the events that led to our current understandings, and because most of these events involved visual design materials, a large proportion of this account will be visual as well.

This leads us to two further caveats: First, because this was a relatively short and minimally funded project, our design work is 'unfinished' in the sense that it did not lead to realised systems that could be tested in the field, but instead ends with the conjectural proposals we produced. Second, we do not discuss all aspects of the project, omitting, for instance, our partners' work (e.g. Sim et al., 2015) and also details of our own Probe study, but instead focus on a few key moments in the process of discovering the island and constructing exploratory design proposals.

Opening: An Invitation to Research

Our story opens with an email from Adrian Friday, Professor of Computing and Sustainability at Lancaster University and a previous collaborator with the authors. The email asked whether we'd be interested in joining him in a bid to the Catalyst project, also at Lancaster, to do research on the island of Tiree. He explained:

> *The ideas are rather sketchy at this point, but essentially: renewable energy is 'time varying' and not always available, and I'm interested in working with a community (e.g. on the island of Tiree…) to explore to what extent people are able to 'sync in' with available green energy and share the resource when it is available, and in understanding the pros/cons of energy that's not 'available on demand'. I keep thinking we're going to end up with some kind of artefact that helps people think about where and when their energy comes from a bit differently…. (Friday, personal communication, May 2013).*

We agreed to pursue this, after some further conversation, because the idea for the project chimed with our previous design research on environmental issues. This had been shaped by critiques tending to undermine simple energy demand reduction as a route towards a lower carbon future. This included empirical work indicating the short-term effects of metering (Abrahamse et al., 2005) as well as the risk of boomerang effects (Schultz et al., 2007). It also included conceptual work including Shove's (2004) insight that energy use needs to be understood in terms of the practices that motivate it, give it meaning, and make it normal, and Strenger's (2013) observation that for many people, changes of practices to reduce demand are difficult or impossible. Finally, our views were shaped by more politically tinged work such as Dourish's (2010) analysis, which suggests that technical approaches such as demand metering assume a market logic of individual rational actors and draws attention to the blind spots of this logic, and Brynjarsdóttir et al's (2012) link of technological approaches to modernism and its limitations.

Based, in part, on these analyses, we had undertaken several exploratory projects concerned with rethinking how design can address environmental concerns. These included, at the time, a project in which we had constructed three 'Indoor Weatherstations' to highlight the microclimate of the home as an alternative to the didacticism of energy demand meters (Gaver et al. 2013); a project with researchers from the Open University in which we hired a graffiti artist to graph a neighbourhood's electricity use directly on their street as a way of exploring feedback at a community rather than household level, and a set of design proposals we had previously developed for devices that would display the National Grid's current demand/supply balance, as a way of encouraging people to avoid consumption during peak periods, when carbon-intensive coal-fired power plants are used to supplement more environmentally-friendly but slower alternatives (Boucher et al., 2012).

Our proposal for devices that would help people adjust their demand to the energy supply seemed particularly relevant to Tiree, as in 2009 a wind generator, called Tilley, had been erected on the island to produce energy. Thus our initial understanding was that a significant proportion of the electricity used on the island was produced locally by a potentially intermittent supply of wind. Given this, it made sense to support community members to adjust their energy use in accord with Tilley's supply, to ensure they were relying on 'green' energy as much as possible rather than drawing on energy from the National Grid. Thus we started discussing ideas about ways of signaling Tilley's supply to the island. For instance, we were intrigued by the idea of building large mechanical structures for visible signaling across distance, which we thought would be much more community oriented in nature than individual computational devices in homes. With these thoughts in mind, we prepared to engage with the island when the funding was granted.

A Drive Around Tiree

Jump ahead to February 2014. Three of us disembark from a small commercial flight at Tiree airport, where we are met by our Lancaster partners and the team of three designers they were working with for their part of the project. We proceed via hire care to a café at the Tiree Trust headquarters, where we settle over our teas to discuss the events of the next few days.

For us, the main purpose of our visit is to get a feel for the island and start thinking about design proposals in situ. To help us do this, we had brought along a few sets of Cultural Probes (Gaver et al., 1999) that we planned to give to islanders. Probes are sets of simple tasks which are designed in the hope of eliciting revealing and inspiring responses from participants. Our set (see figure 1) contained a variety of items, including:

- A set of postcards addressed with suggestive starting lines (e.g. "Dear MP,"; "Dear Energy Company, I really enjoy…"; "Dear Tiree Trust") and appropriate pictures on the reverse side,
- A map of Tiree with a request to use coloured stickers to indicate where people go to meet or be alone, where the power centre of the island is, where enemies live, where to find treasure;
- A book of blank cheques to be filled out with who to pay, how much money, and what to buy, to indicate what residents thought was needed on the island;

Figure 1. Cultural Probe materials.

- An unfinished tourist brochure (“Discover Tiree!”) with suggestive openings (e.g. “Famous for its ____”; “The ____ are not to be missed”);
- A diagram of a solar system asking people to plot their universe: “the people and places you have a connection with”.

We had hoped to find volunteers at the community centre for our probes, but unfortunately there were few islanders around on the day. So instead we set off for a drive around the island in the hope of finding some.

One of the things we learned, driving around on a dry but chilly February day, was that there seem to be few social centres on the island of Tiree. Not only was the community centre quiet, but the sole grocery store was shut and the island’s hotel appeared unoccupied. We finally realised that if we wanted to distribute Probes, we’d have to approach people in their homes. This was not something we’d done before: usually our Probes studies involve volunteers who have signed up to be part of larger projects. Finally, we spotted somebody pulling up outside a house and opening their garage door. Pulling over abruptly, we jumped out of our car, and approached, explaining “Hi, we’re design researchers from London…”. To our surprise, the woman greeted us pleasantly and invited us in for a cup of tea, where we explained the project and handed over the Probes.

We soon discovered that this was not an unusual reception. Instead, every time we pulled over because we spotted a house with solar panels, or accosted a farmer in his field, or talked to a fisherman mending crab traps next to a B&B, we were greeted warmly, found ourselves engaged in talks about the island, and had our Probes received with interest. By the end of the day, we succeeded in distributing seven probe sets, stopping only because the light had faded and it was time for dinner, feeling that we had already learned something about the community of Tiree.

Flashforward: Returns

We didn’t receive responses to the Probes until the weeks following our return to London. Nonetheless we briefly describe some of the returns here to help set the scene for our proposals. To a great degree, the returns (see Figure 2) expanded on what we learned over the course of our visit: that residents appreciate Tiree’s close and friendly community and enjoy the island’s beauty but

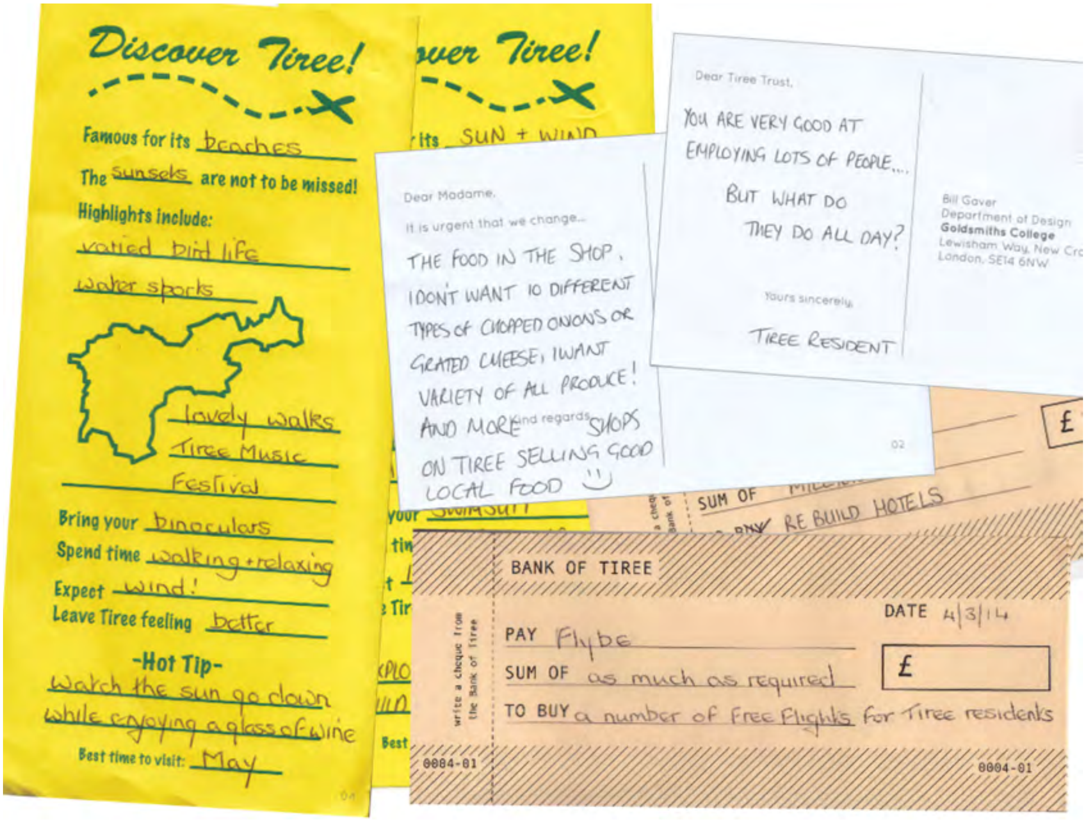

Figure 2. Sample probe returns

sometimes bemoan its fragile links with the mainland. For instance, the tourist brochures laud the '*lovely walks*,' '*varied bird life*' and '*water sports*'. But the cheque books envision money for '*new roads'*, '*free carriage of goods to Tiree'*, and '*a decent boat that can cope with the weather out here'*. The postcards reinforced these themes, and also indicated dissatisfaction with the island's political situation: '*Dear MP: I don't believe you or your cronies in Westminster listen to us… or know where we are?! That's why I'm voting yes for Scottish independence*', with one revealed a kind of teasing scepticism about local arrangements: *'Dear Tiree Trust: You are very good at employing lots of people… But what do they do all day?'*

These returns added to our understandings of the textures of Tiree – not just the issues that concerned people, but the ways they communicate as well. They formed one of the backdrops for the proposals we eventually came up with. Moreover, we found later that the Tiree Trust itself took up the idea of probes, producing their own set a few months later to engage the islanders directly. But that – and the returns as well – happened some time after our visit to the island. In the next section we return there, to our original visit.

A Twist in the Tale

The day after distributing the probes, we took another drive on the island, not to distribute Probes but simply to have a better look around. We wound our way on the single-lane roads, past pastures and fields, rocky shores and rolling hills, stopping to take a look at Tilley, to walk on a beach, to gaze at the spherical, geodesic early-warning station on the highest hill. During this pleasant meandering, we started talking with increasing excitement about the surprising situation of Tiree, which we had heard about first before our arrival on the island but whose import had only hit home while there.

What we learned was this: Despite the fact that Tilley sometimes generates more than enough electricity to power the island, and other times almost none, trying to balance demand with its supply only reflected a narrow view of its relationship with the island. The reason for this is that Tilly was not installed to power the island. Instead, according to the website of Tiree Renewable Energy Limited (TREL), a wholly owned subsidiary of the Tiree Community Development Trust:

> *The principal motivation for the development of Tilley the turbine by TREL was to contribute to the financing of various projects proposed under the island's development plan by harvesting Tiree's most abundant resource. (www.tireerenewableenergy.co.uk/index.php/tilley-our-turbine/)*

Tilley is linked by an underwater cable to the UK National Grid, which pays the Tiree Trust for the energy. This is used to fund various projects on the island. These include a few large investments, including for instance "Tiree Rural Development securing £21,489 towards upgrading the community's Rural Centre", and also a number of smaller awards, which in 2012 included:

- *Tiree Horse & Pony Club £2000 To bring a Horse Riding Instructor to Tiree*
- *Tiree Music Festival £1980 Hire of chemical toilets for TMF & Cattle Show*
- *Tiree Beaver Scouts £500 Activities day at the Hynish Centre*
- *Diamond Jubilee Group £1000 Diamond Jubilee celebrations*
- *Tiree Windsurfing Club £925 Purchase of Body Boards and safety equipment*
- *Tiree Disco Club £1200 Purchase of laptops*
- *Sticky Kids £520 Purchase of infant tables and chairs*
- *Piping Society £2000 To bring a Piping tutor to Tiree*

(http://www.tireetrust.org.uk/historic-windfall-recipients/)

From this perspective, Tilley was not primarily a source of green energy to the island, but of income. Moreover, while the TREL website explains that "Tiree currently uses power from Tilley when there is a demand, however when demand is low power is exported to the mainland via the sub-sea cable" the truth seems much less clear cut. Electricity is like water: once mixed there is no easy way to distinguish sources. So as long as Tilley is connected to the National Grid, then the island's supply is a mixture of Tilley's output with the numerous other sources that supply the grid, and it is questionable whether the island consumes a higher proportion of that output than any other node on the grid, or at least that during Tilley's periods of ample production that the island is consuming only her electricity and not that produced by the coal fired power station on Stornoway, about 150 miles away.

This is not to suggest that Tilley's provision of environmentally sustainable energy was not important to many of the islanders, including the Tiree Trust and TREL itself. Nor is it to undermine the logic of balancing demand with supply, which our partners investigated further (Sim et al., 2015). However, there is no clear inherent link between the electricity supplied by Tilley and consumed by the islanders, and in particular balancing demand to supply, as the initial narrative had suggested, is not a necessity.

And a Further Twist

Another facet of the story of Tilley and the island's infrastructure brought this home even more dramatically. It turns out that the underwater cable that links the island to the National Grid is prone to damage, often by the nets of fishing trawlers. When this happens, the island is cut off from the National Grid's supply. This is the time that Tilley would appear essential, providing a source of energy that is entirely native to the island and allowing it to enjoy independence from the mainland.

But no. The island's infrastructure cannot handle the power generated by the turbine: export to the mainland is essential for it to operate at full power. So when the sub sea cable is ruptured, Tilley has to be shut down almost completely. A diesel-powered generating station opposite the airport is fired up instead.

The irony of the island using relatively 'dirty' energy whenever it is the most isolated from the mainland captured our imaginations. As we discussed the situation, driving around the island, we started imagining design responses to the situation. And when we returned to our London studio, we continued thinking about them, developing them into a workbook of proposals. In the next section, then, we describe some of these proposals as a way of elaborating our perceptions.

Proposals for Tiree

Developing design proposals as part of our process is a long-standing practice in our studio (Gaver 2014). Proposals serve as a kind of hinge between our research into a design situation and the eventual interventions we will make. Developed further than sketchbook treatments, they nonetheless remain open-ended and indicative, often merely consisting of a few images and diagrams combined with small amounts of text to point in a direction for design without specifying it in detail. In addition, they range from the playful to the serious, using exaggeration and humour to highlight issues and possibilities. They combine implicit summaries of what we have learned with ideas for how we could develop new possibilities appropriate for the situation. Gathered together to form a workbook, they form a 'design space' in which individual proposals serve as landmarks and the spaces around them represent opportunities for further ideas.

Here we describe a subset of key proposals from the 38-page workbook we produced.

Marble Run

The Marble Run (Figure 3) is a proposal for a mechanical sculpture that would animate the flow of energy and money on the island, to raise awareness of citizens. Marbles of different colours representing units of electricity generated by Tilley and other sources on the National Grid (coal, nuclear, other wind, etc.) would flow along channels eventually ending in homes. Meanwhile, other

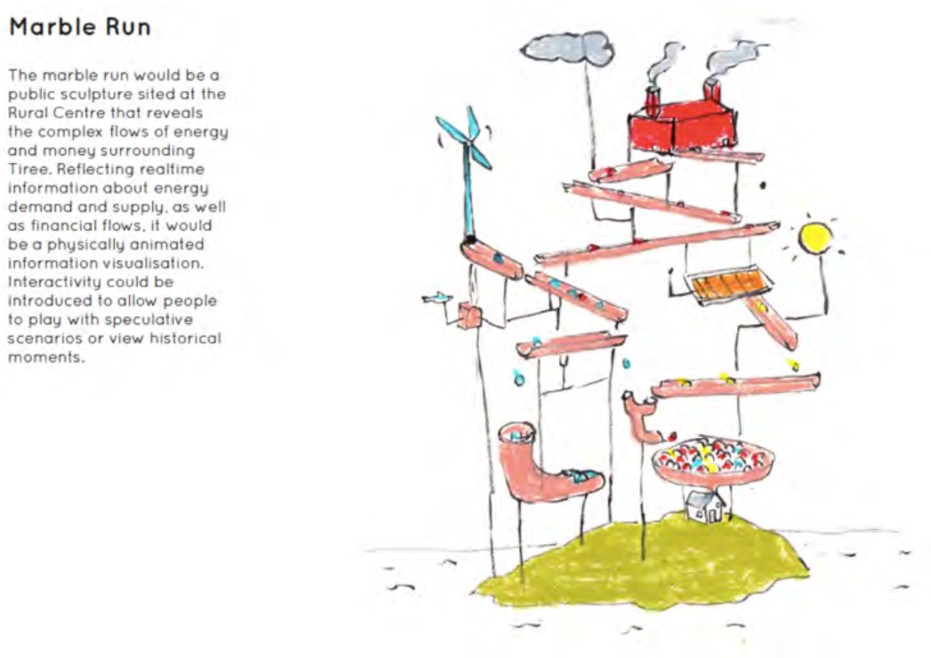

Figure 3. The Marble Run would be a public sculpture showing the flow of energy and money on Tiree in realtime, to raise citizens' awareness of the current situation.

coloured marbles representing money would flow on channels from homes to the National Grid, with a subset returning to the Tiree Community Centre and on to recipients of grants.

Periodically, the channel representing the sub-sea cable would be blocked. Tilley would stop producing marbles, and new marbles (a sludgy grey, no doubt) would flow from the island's diesel generator instead. The flow of money from the National Grid to the Community Centre would stop as well. This would vividly illustrate the irony of having an island-based wind generator that does not produce energy independence for the island.

Energy Broch

Similar to the Marble Run, the Energy Broch (Figure 4) would visualise flows of energy and money on the island. This proposal suggests, however, that the visualisation would be created from the natural materials on the island, by islanders who would adopt its maintenance as a routine practice pursued over months or years. Based on the traditional stonework on the island, different colours or shapes of rock would be moved to different sites on the island, slowly migrating to reflect energy flows. Over time, we imagined, this new activity would become a tradition on the island, one that residents could own and modify, and one that might eventually stir interest amongst tourists and anthropologists as well.

Boat Tow

Many of the islanders complained to us about the inadequacy of the current ferry to the mainland, which apart from the small flight from Glasgow is the only regularly scheduled means of transporting goods to and from the island. The ferry is often unable to cope with rough weather, which means the island has to do without fresh supplies for weeks at a time.

This proposal suggests decommissioning the current ferry, and mounting it on a set of tracks running from the shore up the side of one of Tiree's hills (Figure 5). A winch system would drag it up the hill slowly, using any excess energy generated by Tilley after supplying the islanders' needs and thus allowing the generator to be disconnected from the National Grid or at least to continue running when the cable is cut. The boat would serve as a form of battery, storing energy that could be released when Tilley's output is down and furthering the island's ability to achieve self-sufficiency.

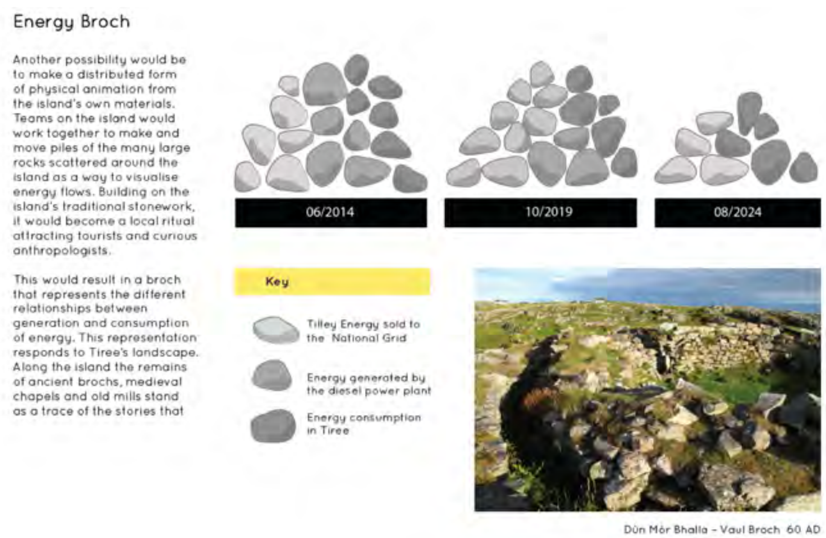

Figure 4. The Energy Broch would be constructed by islanders moving stones around the island to create material representations of energy flows on the island.

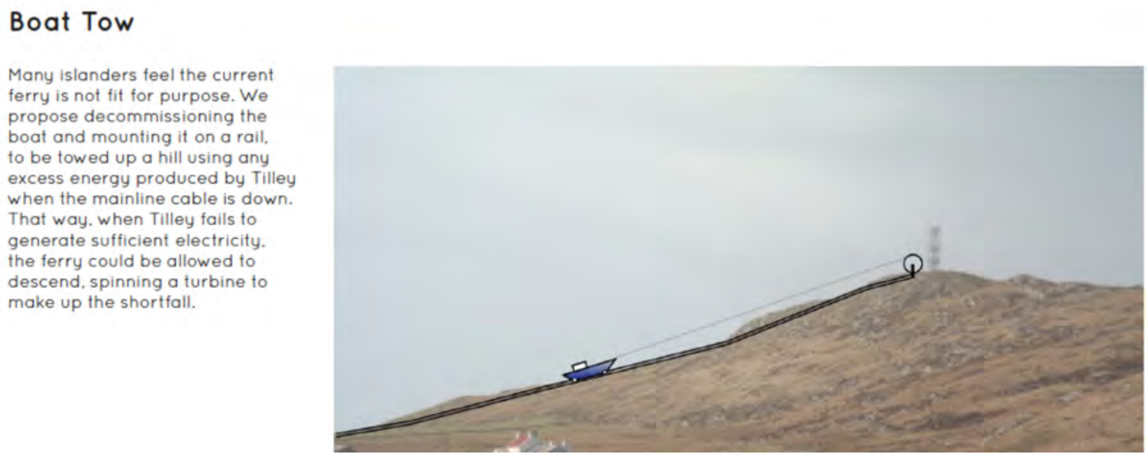

Figure 5. Boat Tow suggests a novel method for storing excess energy generated by Tilley.

We asked a physicist to calculate the energy implications of such a system. Assuming a 5km track at an average slope of 5%, using the actual boat weight of 3,500 metric tonnes, and assuming that the generator and winch systems each have an efficiency of 70%, it would take roughly 1.92×10^{10} Joules to drag the ferry up the hill, while letting it roll down again would provide roughly 9.43×10^{9} Joules. This is equivalent to about two barrels of oil to raise the boat, and about one barrel released on its descent (which is a fairly dramatic representation of how much energy is stored in a barrel of oil) [1].

With an overall efficiency of about 50%, the boat tow system compares badly to the 92% efficiency claimed by, for instance, Tesla's Powerwall (https://www.teslamotors.com/en_GB/powerwall), a battery array designed to store home-generated electricity. Nonetheless, the public demonstration of Tilley's energy at work might justify this loss, as might the sight of the ferry finding a purpose for which it is better suited than its current one.

Hydrogen Economy and Glass Lake

Hydrogen Economy (Figure 6) proposes using the energy Tilley generates to produce hydrogen. This could become the fundamental fuel for the island, as it is carbon neutral and amenable to storage. In addition, hydrogen could not only be used to generate electricity, but also to heat houses and fuel cars and other vehicles.

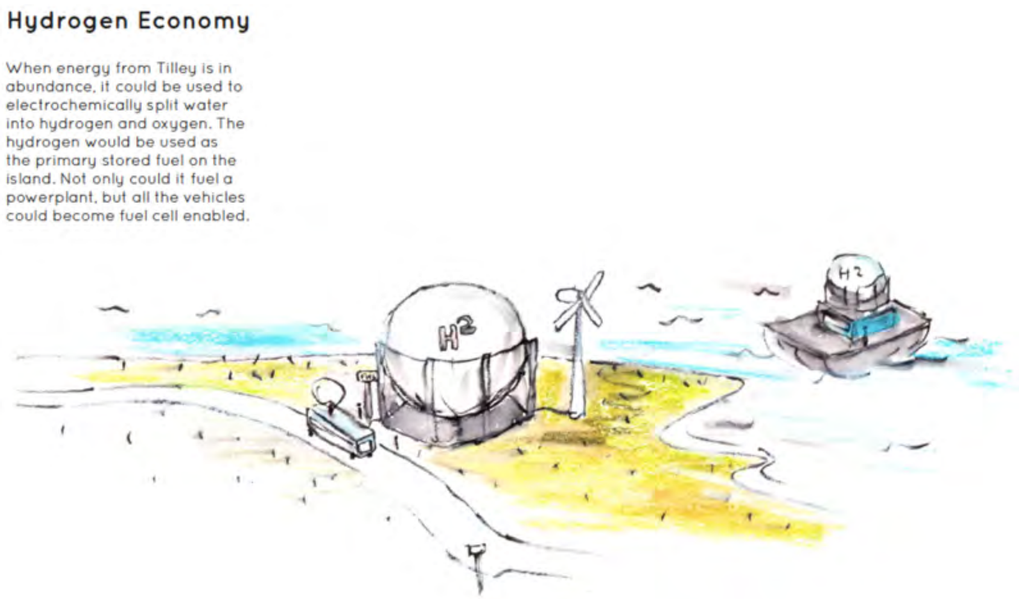

Figure 6. Hydrogen Economy suggests using Tilley's power to produce an alternative fuel.

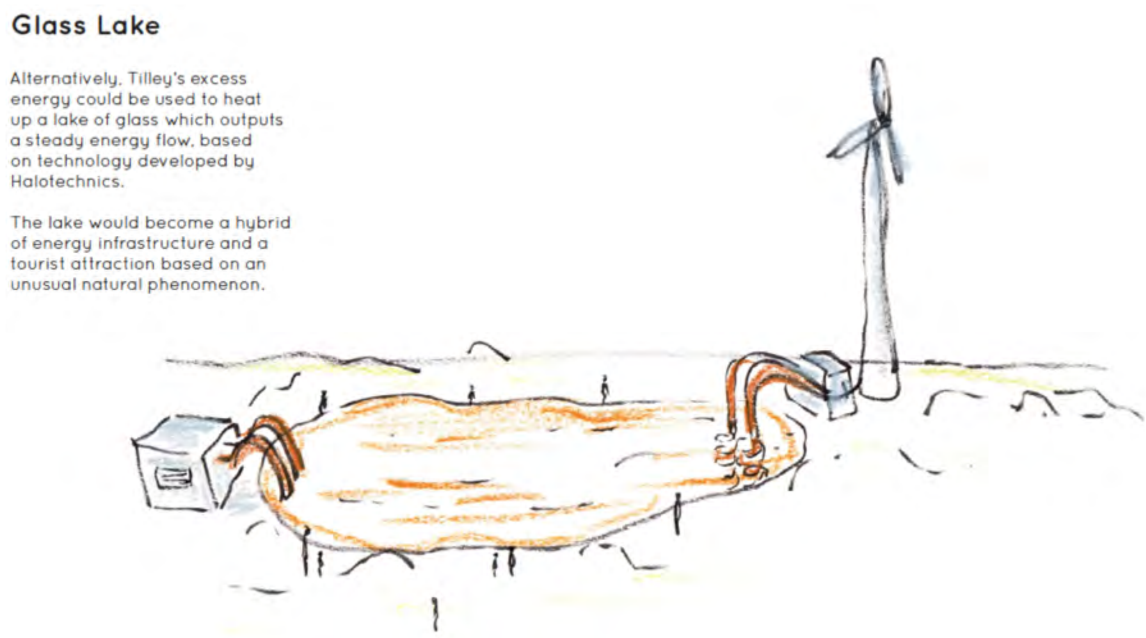

Figure 7. Glass Lake envisions a novel way to store the energy produced by Tilley.

The Glass Lake (Figure 7) is based on a technology developed by Halotechnics (halotechnics.com), a company with the mission to develop "economically viable renewable energy storage using advanced materials and innovative systems engineering". Its product Haloglass RX is a 'high temperature thermal fluid' – basically a kind of glass – advertised as suitable for "Grid scale thermal electricity storage systems". Though normally the material would be insulated to maximize efficiency, we propose using it to create a large lake of glass near Tilley (Figure 5). Energy could be alternately stored by and drawn from the lake, allowing it to serve as another form of battery. Not only might local customs evolve in response ("reckon I'll go take a look at how much energy the lake's showing"), but it could be developed as a major new tourist attraction for the island.

Hydrogen Economy and Glass Lake join Boat Tow as proposals for novel forms of energy storage for the island. Beyond this, however, they reflect other concerns on the island – the inadequate ferry, the motor traffic, the tourist industry – and indicate how entangling the electricity infrastructure with these concerns might lead beyond generic, strictly utilitarian solutions towards those that fit and add value to Tiree's particular circumstances.

Cryptocurrency Wind-Mining

The proposals above focus on Tilley as a source of electricity for Tiree, and in particular suggest that rather than selling the excess power to the National Grid it could be stored for use when wind is low or the underwater cable is down. As we have seen, however, the fact that Tilley generates electricity is arguably less important to the island than the income it produces. After all, the island does not directly use Tilley's electricity, and consumers pay for the energy they draw from the National Grid, including whatever proportion is produced by Tilley. From this point of view, Tilley's main function is to provide funds for the Tiree Trust, and the more efficiently this can be done the better.

Our proposal for Cryptocurrency Wind-Mining (Figure 8) reflects this perspective on the motivations for Tilley. It calls for Tilley's power to drive the high-powered computers necessary to mine new cryptocurrency coins. These could be sold directly with the marketing advantage that they would be far more environmentally sustainable than coins mined on rigs that rely on carbon fuels. This could

Figure 8. Wind generated cryptocurrency would focus directly on generating income for Tiree.

well prove a more lucrative[2], and thus more efficient, use for Tilley's output than the current one, and the proceeds could be used to fund the Tiree Trust and also to pay for the continual upgrades of computing equipment needed to maintain competitiveness at cryptocurrency mining.

Two Tilleys, a Land Bridge, and Tiree's trajectory

If the surplus electricity generated by Tilley could be handled, either through some form of storage or by using it close to the source (e.g. to mind cryptocurrency coins), then more wind generators could be installed on the island (Figure 9). This possibility raises fundamental questions about Tiree's future. One alternative would be to use the additional electricity to reduce or eliminate reliance on the National Grid, putting the island on the path towards greater self-sufficiency and even complete autonomy from the mainland. Another alternative, however, would be to continue selling energy to

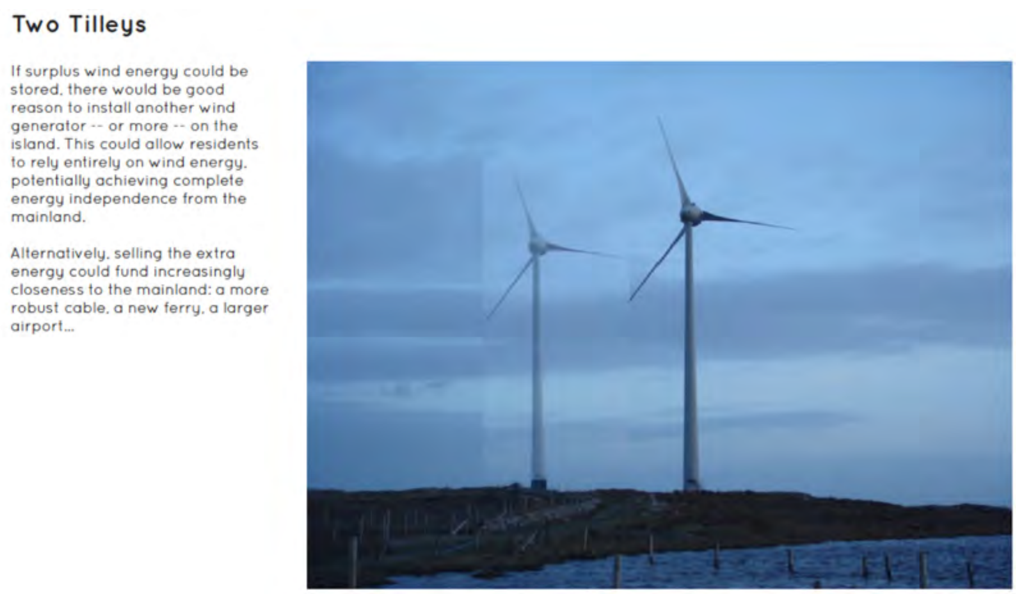

Figure 9. Improving the infrastructure could allow an expanded array.

the National Grid, and to use the increased income to strengthen the infrastructures binding the island to the mainland.

Ultimately the funds could be used to build a land bridge between Tiree and the mainland (Figure 10). We saw signs of this impulse in the islanders' complaints about the ferry, the lack of goods in the local shops, and the cost of flights and difficulties of travel. The relative inaccessibility of Tiree may well be the reason that it maintains large areas of undeveloped coastline and enjoys a peaceful, friendly culture. The advantages of easy movements of goods and people might seem to outweigh this appeal for many on the island, however – and developing Tilley might be a tipping point in the current balance between solitude and convenience.

Discussion: Tilley, Proposals, and Entanglement

It should be clear that our proposals were not seriously intended for development. Nonetheless, they are all technically possible if not culturally plausible. They were developed, and intended to be received, in a somewhat playful spirit, a frame of mind which is conducive to speculation about issues and possibilities that might be dismissed from more 'serious' points of view. Knowing that the scope of the project would not allow us to realise our proposals helped us to achieve this frame of mind and to imagine systems at a scale we would be unlikely to build. Thus, similar to some architectural proposals (see e.g. archigram.westminster.ac.uk), our proposals were not intended to seek solutions so much as to ask questions, presenting exaggerated and fanciful scenarios as a way of discussing existing situations and future possibilities. Overall, the proposals helped us to think through several aspects of Tiree's situation. They also served as a resource for discussing our perceptions with our partners and with the islanders, to whom we presented the proposals at a community event.

One of the main lessons we learned on Tiree and reflected in our proposals is that despite being an island Tiree is thoroughly entangled with the mainland. This is clearly the case for its energy, where we found that even Tilley, the most promising means of achieving sustainable energy independence, is dependent on the National Grid to keep running. The diesel generator, too, depends on regular supplies of fuel that must be shipped in by ferry – which also brings food and other goods, including

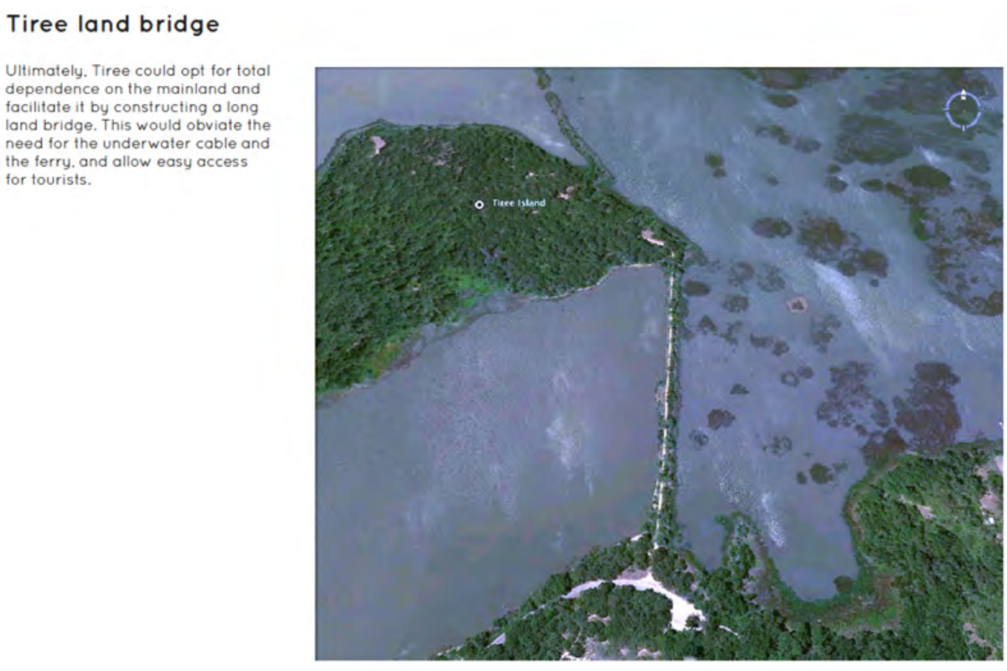

Figure 10. Ultimately, a land bridge might be the most desirable solution for Tiree.

tourists upon whom much of the local economy arrives. The more we looked, the more we recognised links and ties to the mainland. We began to realise that achieving true energy independence via Tilley currently has more to do with the underlying infrastructure to which the generator connects than it has to do with demand/supply balance. That is, what is required most of all is some way of storing the electricity Tilley produces, especially when the subsea cable is down. But it may be that Tilley's connection to the National Grid is more desirable than achieving independence in the first place. After all, connecting Tilley to the National Grid allows the energy she generates to be combined with sources across the nation, so local fluctuations can be compensated for by oversupplies elsewhere. From this point of view, the National Grid may be the best battery of all.

Our proposals also point to ways in which energy is, or could be, entangled with other activities and concerns on the island. These are congruent with other to 'materialise' energy attempts (e.g. Pierce & Paulos 2010; Backlund et al., 2007), and contrast with more typical approaches that treat energy as a commodity to be produced and distributed invisibly, efficiently, and homogenously. In Latour's (2007) terms, energy is an issue that has passed beyond public controversy to become 'settled' in infrastructure. The situation with Tilley and the cable disrupts this settlement, however, and our proposals build on this to bring further issues into play. They overtly link the island's energy to other values – transport, tourism, finance and convenience. They question whether Tilley is about energy or about money, and probe the Tiree Trust's role in collecting and distributing funds. They also seek to explore the balance between financial and environmental criteria and other possible values. Would it be worth compromising energy efficiency for the spectacle of a boat being dragged up a mountain, or a lake made of molten glass? Is it enough to generate sustainable electricity, when this might be used to produce more widely usable fuels? Or is sustainability merely a marketing tool for tourism or other money-making activities? Ultimately the proposals suggest that how Tilley is treated connects to more fundamental issues of the island's trajectory with respect to the mainland. Our proposals don't settle any of these issues . On the contrary, they help bring them into view in a way that might usefully complicate understandings of how energy is and may be lived on the island.

References

Abrahamse et al.: A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology* 25(3). (2005).

Backlund, S., Gyllenswärd, M., Gustafsson, A., Ilstedt Hjelm, S., Mazé, R., and Redström, J. (2007) STATIC! The Aesthetics of Energy in Everyday Things. In: Design Research Society Wonderground International Conference 2006, 1-4 November 2006, Lisbon, Portugal.

Boucher, A., Cameron, D., and Jarvis, N. (2012). Power to the people: dynamic energy management through communal cooperation. Proc. DIS '12, 612-620.

Brynjarsdottir, H., Hakansson, M., Pierce, J., Baumer, E., DiSalvo, C., and Sengers, P. 2012. Sustainably unpersuaded: How persuasion narrows our vision of sustainability. *CHI 2012*, 947-956.

Dourish, P. 2010. HCI and environmental sustainability: The politics of design and the design of politics. *DIS 2010*, 1-10.

Frayling, C. (1993). Research in Art and Design. Royal College of Art Research Papers 1, 1.

Gaver, W. (2012). What should we expect from research through design?. Proc. CHI'12, 937-946. ACM.

Gaver, W. (2014). Science and Design: The implications of different forms of accountability. In Olson, J. and Kellogg, W. (eds.), *Ways of Knowing in HCI*. London: Springer, pp. 143 - 165.

Gaver, W., Bowers, J, Boehner, K, Boucher, A, Cameron, D, Hauenstein, M, Jarvis, N, and Pennington, S (2013). Indoor Weather Stations: Investigating a ludic approach to environmental HCI through batch prototyping. Proc. CHI'13.

Gaver, W.W., Dunne, A., and Pacenti, E.. (1999) Cultural Probes. *interactions* magazine. vi(1), pp. 21 - 29.

Latour, B. (2007). Turning around politics: A note on Gerard de Vries' paper. *Social Studies of Science*, *37*(5), 811-820.

Pierce, J. and Paulos, E. (2010). Materializing energy. Proc.DIS '10, 113-122.

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The constructive, destructive, and reconstructive power of social norms, *Psychological Science*, 18(5), 429–434.

Simm, W., Ferrario, M.A., Friday, A., Newman, P., Forshaw, S., Hazas, M., and Dix, A. (2015). Tiree Energy Pulse: Exploring renewable energy forecasts on the edge of the grid. Proc. CHI '15, 1965-1974.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. Proc. CHI'07, 493-502.

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[1] The calculations:

Mass = 3500*1000 kg;
Gravity = 9.81 m/s^2;
Height = N[5000*Sin[(5/100)*Pi/2]]

total energy = Mass*Gravity*Height = (1.34695*10^10 kg m^2)/s^2

or, total Energy = 1.347*10^10 Joules

Note : From Wikipedia : "The gigajoule (GJ) is equal to one billion (10^9) joules. 6 GJ is about the amount of potential chemical energy in a barrel of oil, when combusted"

So,
Mass*Gravity*Height/(6*10^9 kg m^2/(s^2*barrel)) = 2.24491 barrel

I think that the efficiency of a generator is 60 - 80 %. Taking a midpoint 70 % efficiency the output would be

0.7*Mass*Gravity*Height = (9.42863*10^9 kg m^2)/s^2
This is about a barrel of Oil.

I haven't taken into account the energy necessary to bring the train up. I assume that with a 70% efficiency the energy required for this would be (1/0.7)*Mass*Gravity*Height = (1.92421*10^10 kg m^2)/s^2 or about 2x10^10 Joules.

with 70% efficiency in and 70% out, the total efficiency is 0.7*0.7 = 0.49 or about 50% efficiency.

This does not take into account frictional losses from the tracks, wind resistance, etc, etc.

[2] A single bitcoin currently trades at about £300.