Community Carbon Footprints and the Climate Transition: An Initial Assessment for Treherbert

Calvin Jones
Cardiff Business School
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Headlines

- We estimate the consumption carbon footprint for Treherbert, a small community in South Wales.
- Our results suggest an annual household footprint of around 47,000 tonnes with a further 11,000 tonnes attributable to industry located within the Ward.
- The emissions are fairly equally distributed across the range of sources and uses, suggesting there is no single, dominant action to progress to net-zero: wide ranging and integrated actions are required.
- Less important in the overall footprint for this community is commuting, and land-based carbon sequestration opportunities will be limited, even though Treherbert is surrounded by extensive treescapes.
- Actions to move to net-zero must include deep and meaningful engagement, if no co-creation with, communities that have hitherto been largely ignored in the development of public policy

Introduction

The need to transform production, consumption and transport (essentially, lifestyles) to respond to the climate (and nature) emergencies is stark and urgent. This is particularly so in the developed world, where per-capita and per-household greenhouse gas (GHG) emissions are highest, as is responsibility for historic/cumulative emissions (Hickel, 2020). Additionally, developed economies are most able (if not so far willing) to reduce the fossil energy use, materials throughput and consumption of high-greenhouse gas foodstuffs, that drive climate heating whilst still providing relatively high standards of living (Büchs & Koch, 2019). A 'just' transformation however must recognise that even in rich nations, many people and places are already suffering from significant hardships related to increasing energy and food costs, and from disruption to socio-economic systems that, whilst by no means all climate consequent, will likely get worse as climate heating progresses.

It is widely acknowledged that these transformations will require interventions, incentive and behavioural changes at different spatial scales, by both organisations and people, and in land uses. Thus, we see the adoption of climate-mitigation actions (and promises of such) at national and regional levels, and by both public, private and third sector bodies, whilst there is copious advice on how individuals and households can change their behaviours and their dwellings to reduce emissions - for example by switching from private to public (or active) travel, by reducing red meat consumption, or by installing insulation, renewables or heat pumps in dwellings[1].

There is however something of a gap in both the debate, and in evidence-based advice and guidance on reducing emissions. This gap is at the level of the geographic community. There is relatively less information, let alone intelligence, on the estimation of community-level GHG footprints, or on appropriate community-level action to reduce these footprints. In a 'developed country' contexts Lombardi *et al* (2017) provide an overview of progress at city-scale (and see Jones & Kammen, 2011 for a 'top down' US example, and Dhakal & Ruth 2017 for broader discussions). For smaller communities there has been limited progress, possibly due to difficult data and 'bounding' considerations (but see Barthelmie *et a*l 2008 for Biggar in Scotland). Geography and community however remains important as a context for social interaction, and the shaping of identity, behaviours and views (Bell & Yorke, 2010; McNamara et al 2013; Olson, 2019), not least with respect to the environment (Zhang *et al* 2018; Weckroth & Ala-Mantila, 2022).

Levering the community-scale for decarbonisation efforts is therefore important. Understanding community responses to climate interventions, messaging and options may be necessary to enable rapid, effective and widespread acceptance and implementation, and in judging the potential for unintended consequences and injustice in climate transformations. This is especially important because many (if not most) communities inside developed countries, but outside favoured global 'cores' have experienced long periods of economic decline, political unimportance and cultural anomie, leading to a range of problematic outcomes (MacKinnon et al

[1] See https://cat.org.uk/info-resources/free-information-service/green-living/carbon-calculators-ecological-footprints/

2022): put simply, many communities are, after such a long period of decline and insignificance, not in the mood to listen to outsiders (Abreu & Jones, 2021).

Engaging with communities on the decarbonisation agenda then requires both a reasonably robust (and hopefully bespoke) estimate of community carbon footprint[2] with which to raise carbon literacy and contextualise and drive change, and then some measure of ownership or control over relevant processes, infrastructure and capital (Cowell *et al* 2011). This paper reports on the initial stages of such a process, undertaken with the community of Treherbert, a former mining community in the south Wales valleys. Here we report an initial 'baseline' carbon footprint for the geographic community, noting the data and conceptual issues inherent in the estimation, and place this footprint within a discussion of where action at this community scale can (and cannot) help create a zero carbon, fair and responsible future.

Why Treherbert?

Treherbert is a small village (pop 5,800 in 2019) in the heart of the former south Wales coalfield, the largest in the UK (United Kingdom). It is many ways typical of its type. Situated at the top of the Rhondda Fawr, mining and manufacturing employment lost particularly since the 1970s (including in 2007 the Burberry clothing factory in neighbouring Ynyswen) has not been replaced with similarly valuable or extensive employment. Three of Treherbert's four Super Output Areas were in the top quartile in Wales' Index of Multiple Deprivation in 2019[3]. More generally, the village suffers similar socio-economic ills to alike places in the valleys as described over many years by Beatty *et al (*2019). It has a settled and slow-changing population - for example the 2011 Census reported 98% of residents were born in the UK compared to 95% for Wales (and 86% for England). The area was, in 2011, overwhelmingly white (98.6%).

So far, so 'Valleys'. However, Treherbert is different. Firstly, it is surrounded by exceptional geology, including the stunning Pen Pych mountain, and with the

[2] A shorthand for the basket of greenhouse gases, reported throughout as CO2 equivalents (CO2e)
[3] https://gov.wales/welsh-index-multiple-deprivation-full-index-update-ranks-2019

landscape offering a number of climate mitigation opportunities (Llewellyn *et al,* 2019). Secondly and relatedly, the community has a geographically close (yet economically more distant) relationship with renewables; surrounded by, and providing access to, the 228MW Vattenfall-owned Pen-y-Cymoedd wind farm. Thirdly, the village has a (relative to most other Welsh places) well developed and well regarded community development and enterprise sector with *Welcome to our Woods* and *Project Skyline* joining forces to lever (over a number of years) significant charitable and government funding with varied objectives, including community economic regeneration, social prescribing for health and wellbeing, renewables installation, the development of new community services and buildings and, most relevant here, the development of a ground-up vision(s) of a sustainable community future[4].

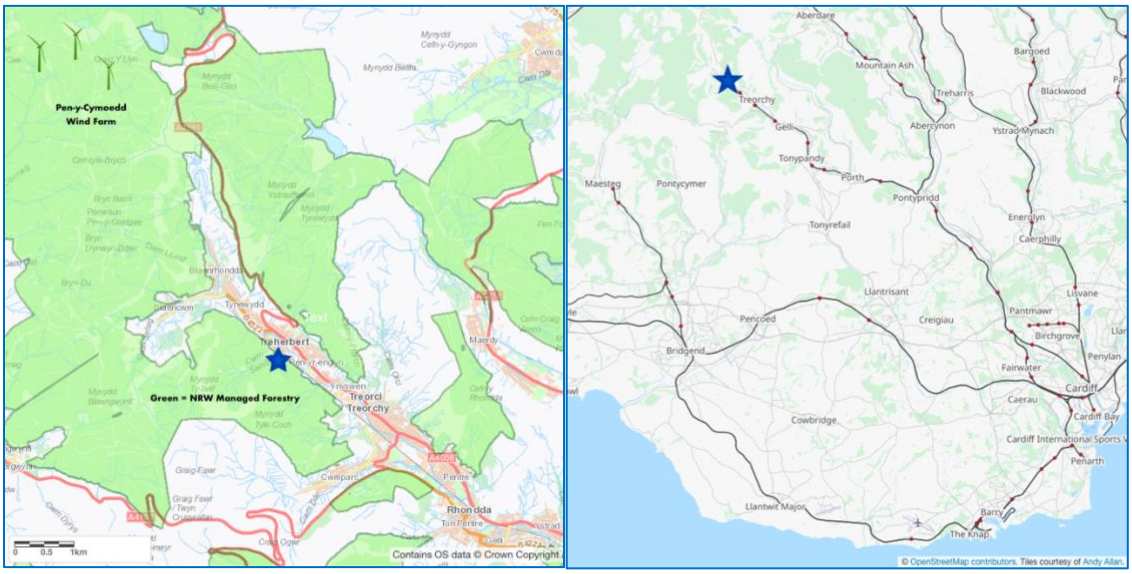

Figure 1 – Treherbert in its Geographic Context

Treherbert is additionally surrounded by extensive land, mostly forested and managed by Natural Resources Wales (NRW), the country's environmental management body, and on which the wind farm sits. Collaboration between NRW and community bodies has resulted in the (current) development of a co-created, long term, landscape management plan, and agreement to involve the community more in on-the-ground landscape and forest management. This partnership raises

[4] See https://welcometoourwoods.org and http://www.thegreenvalleys.org/our-projects/skyline/

the prospect of different uses of the land, including increased carbon sequestration through silviculture and peat-bog remediation, a 200 Ha nature reserve, and the development of wood-products with localised value chains, potentially feeding new timber-framed, carbon-holding social housing (Welcome to our Woods, 2022) Employment and income, then, may also result.

Within this rich context the derivation of a (baseline, secondary data-based) community carbon footprint is a useful tool for understanding where Treherbert's climate impacts originate, providing a resource and 'talking point' for the community to recognise, digest and respond to its current carbon position - and to consider what options for reduction are doable and acceptable, and in what order. For Treherbert especially, we might also discover whether the landscape provides opportunities to capture carbon (annually) at a similar scale to any hard-to-extinguish emissions – providing, if you will a local and verifiable 'offset' for those emissions. An additional outcome will also hopefully be an enthusiasm to help 'build a better footprint' through the provision by community members of detailed and up to date behavioural, altitudinal and consumption information. As the following sections reveal, existing published and modelled data is unlikely to be of sufficient quality to guide the choice this, or other UK communities, might seek to make.

Estimating Treherbert's Carbon Footprint: Caveats

We seek here to estimate the greenhouse gas emissions associated with the activities of Treherbert's resident population. We additionally report the emissions associated with the public services they consume, and estimate those related to employment locations within the geography (here the electoral ward). Across all domains – housing-related, transport, food and drink, other household purchases – we seek to measure as extensively as possible by including embedded/supply chain emissions, although this is not always possible. For example, our estimates of greenhouse gases consequent on within-ward employment include only gases emitted in Wales and the rest of the UK (directly and along supply chains) with the relevant accounting structures (the Input-Output Tables for Wales, 2019 base year[5]) yet to benefit from integration into global carbon accounting frameworks.

Whilst adhering to a notional ‘2019 footprint’ (the most recent pre-pandemic and hence illustrative year), our data are necessarily drawn from across a number of years, and are either bespoke to the locality (e.g. the 2011 Census data for the village) or abstracted from academically published papers from which inference to Treherbert is drawn (e.g. on food-related emissions). Full detail on the estimation process, choices and (often problematic) data sources is available as Annex 1. There are however two key points to make about the nature of our estimate.

Firstly, the community footprint must be viewed alongside other carbon footprints that relate to the community; there will be overlap and double counting. For example, the tonnes of carbon reported here under ‘commuting’ impacts will be the same gases as reported by Transport for Wales (TfW) in its carbon accounting insofar as Treherbert residents use TfW trains to commute; meanwhile our estimate for public services provision is effectively a subset of that reported by Welsh Government (Jones & Munday, 2021). Inherent here are issues of the ‘bounding’ of community carbon responsibility. For example, we estimate and report emissions associated with employment sites within Treherbert (notably TfW and Everest, a large window manufacturer), and these are likely duplicated elsewhere, but we do not include here the emissions of associated with Treherbert residents’ employment outwith the ward. We have made the relevant choices here we consider most useful to present the emissions of Treherbert ‘as a place’, but other choices can be made. These overlaps and conceptual issues might raise interesting issues if, in the future, communities vie with organisations and businesses to ‘claim’ carbon savings in areas of overlap.

The second, important point to make is that what follows is not Treherbert’s actual carbon footprint: it is a reasonable estimate of the GHG emissions consequent on residents’ spending[6] on relevant goods and services, using all available published data that in the in the best case relate directly to Treherbert, but in other cases are applied to

[5] Currently unpublished – please contact the author for further details.
[6] And indeed, current spending; there is no capital/investment spend included, although consumer durable spend is.

the population or households of the village from local authority, Welsh, or UK aggregates or estimates, amended using relevant related metrics (e.g. income levels) where appropriate. Also, the Census data are very old, although future footprints will benefit from upcoming results from the 2021 UK Census of Population. The following sections thus represent an *illustrative* footprint, but one that can spur debate and encourage refinement, whilst improving carbon literacy through a revelation of the key the carbon sources and of our estimation techniques (Annex 1).

Treherbert's Carbon Footprint

We estimate the greenhouse gas footprint for Treherbert households at 46,880 tonnes of carbon-equivalent emissions in (notionally) 2019, with a further 11,070 tonnes of CO2e (CO2 equivalents) associated with employment sites in the village. The biggest portion of these emissions are associated with food and drink – although these data are the least 'bespoke' to the area. Other household spending accounts for 12,840t and with housing energy and transport at around 10,000 tonnes each.

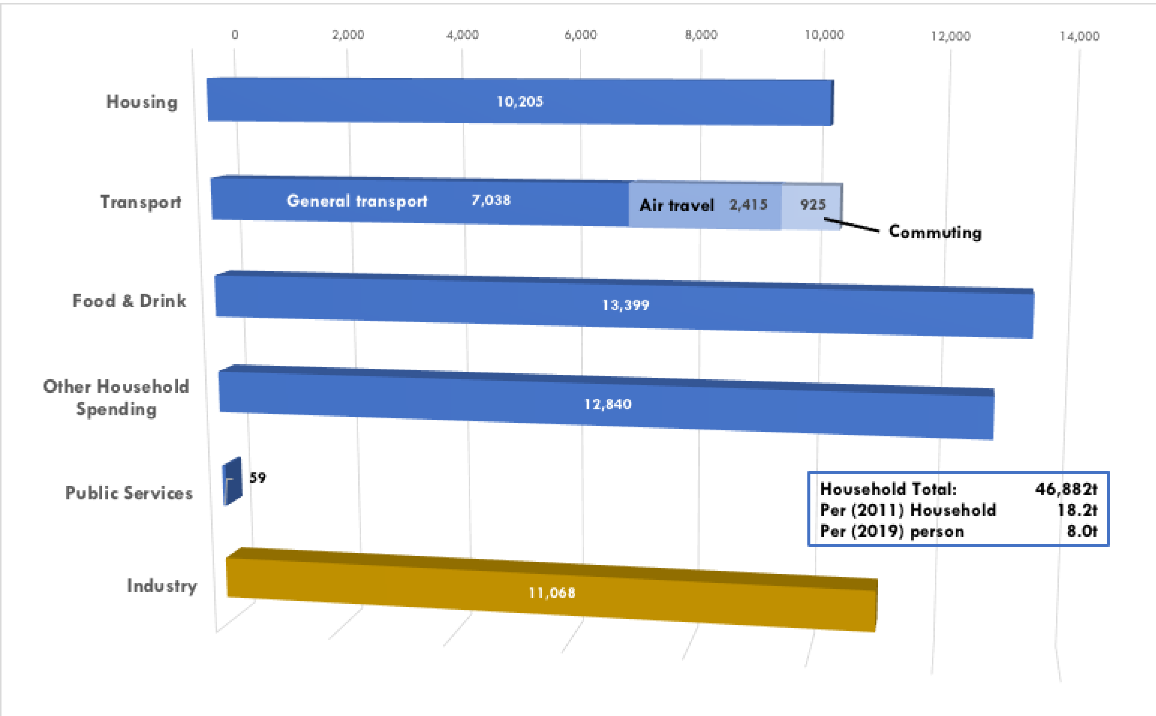

Figure 2 – The Treherbert Carbon Footprint (tonnes CO2e)

Notable, then, is the relatively even distribution across emissions sources – there is no single 'silver bullet' here that will address the bulk of emissions issue *en route* to zero carbon. *Every* part of life must be transformed in terms of both energy sources, and/or functional form, requiring sustained engagement, investment and behaviour change across multiple inter-related domains – and *quickly*. Our numbers also reinforce the sheer scale of the carbon reduction problem, even for poorer communities in the developed world – and of course where the ability to invest in mitigation (insulation, electric vehicles) is, at household and aggregate community level, lower than in richer places. This will of course have implications for the cost of living and wellbeing within places like Treherbert, with older and more carbon-intense houses, jobs and transport, as well as for the global climate (Jones, 2010; Owen & Barratt, 2020).

We can however, even from these incomplete data, start to see how effort may be effectively directed. For example, there has been much discussion of how post-COVID19, changes in employment behaviours and increased 'working from home' might bring multiple benefits, including for GHG emissions[7]. Here however our data suggest (albeit for 2011 commuting) that the potential savings are relatively modest for this community (approximately 30km from the major employment centre of Cardiff, benefitting from twice-hourly train service). Any carbon benefits from reduced commuting might be significantly diminished by increased (fossil) home-heating and power emissions. Even if not, the complete elimination of commuting would reduce the community footprint by no more than 2%.

Assessing the Community Role in GHG Reduction

The potential for carbon reduction (and elimination) for each of the five emissions drivers reported in Figure 2 has been subject to significant attention. Those discussions – on technical and behavioural options, feasibility, and costs – are not presented here, but Allen *et al* (2019); Miller (2019) and Welsh Government

[7] https://grist.org/climate/working-from-home-is-erasing-carbon-emissions-but-for-how-long/

(2021) are a useful introduction to the issues in the UK and Wales [8]. Rather, given the scope of this paper, we wonder what, might be done at the level of the small geographic community to drive decarbonisation in each of these emissions drivers. It is clear that in all five areas, change is needed from the most macro to most micro scale. Very little will work – and work quickly – without understanding and buy-in from 'ordinary people'.

Housing

In April 2022, the energy strategy for the UK government made it clear that whilst the electricity supply-side would benefit from new nuclear and offshore wind (though less it seems from cheaper onshore wind and Solar PV), in terms of energy efficiency and heat, householders are left largely to 'figure it out themselves' with no clear, consistent and holistic approach to funding a housing transition (BBC, 2022). Given the resource limitations of the *Welsh* Government in finding the sums likely required to transform the old and leaky housing stock of Wales, this is an especially significant issue for the residents of poorer communities (Jones, 2022). Whole-house efficiency and power/heat supply retrofit costs for the dominant stone-built stock types are likely to range up to £30,000 (or now, more, Jones *et al* 2017) and in a community where the median household income was in 2019 around £16,000, 75% of the UK average[9]. The situation then is stark, likely requiring significant additional (outside) resource. Specific subsets of Treherbert and communities like it have more scope; for example, registered social landlords (housing associations and councils) could perhaps lever their ability to borrow against future income, and more 'strategic' potential (e.g. undertaking a whole-house refurb between tenants). Both locally (to Treherbert) and across Wales, the role of social landlords in the housing transition, including understanding the role of zero carbon, local bio-materials in new build, is a live issue[10]. Specifically at community scale however, opportunities might be more limited Although in Treherbert's case, there is potential for community-delivered renewables to impact, more important might be a

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[8] And also more generally https://www.iea.org/topics/climate-change
[9] https://statswales.gov.wales/Catalogue/Business-Economy-and-Labour-Market/Regional-Accounts/Household-Income/grossdisposablehouseholdincome-by-area-measure
[10] See https://www.insidermedia.com/news/wales/new-timber-frame-housing-factory-under-development for a Welsh Government/Housing Association supported new factory.

greater acceptance of change driven at a (geographically) higher scale that the involvement of a climate-sophisticated community organisation might bring (Cherry *et al* 2022).

Transport

Treherbert; relatively compact, (historically) socially tight-knit, and with (literally) one road in and one road out, would seem to be fertile ground for community level transport provision that might impact on lifecycle carbon from vehicles, and make the difficult transition to (individually owned) Electric Vehicles (EVs) moot. So far, such car sharing schemes have not far developed beyond the UK's cities, and certainly not in the South Wales valleys[11]. A number of potentially travel-reducing opinions are on the table for local social enterprises, including co-working space in the to-be-constructed community building near the railway station; an e-Bike club; and more local food provision, with this current analysis a first step in framing these choices (Welcome to our Woods, 2022). Meanwhile for air travel, around 25% of community travel emissions, it will be interesting watch how far the 'flight shaming' and similar movements become mediated and driven at local level. So far, the debates have largely been seen through an individual lens (Flaherty & Holmes, 2020; Gössling et al 2020).

Food & Drink

Evidence suggests there is potential for significant carbon reduction from changes in both the production and distribution of foodstuffs (Vidergar *et al* 2021) and changes in diet – for example Hoolohan *et al* (2013) suggest realistic dietary changes (that are healthier) can reduce emissions by 25% over UK baseline. Again, we have the dual (but uncertain) decarbonisation drivers at community level: behaviour change, and more local provision. In this (and similarly challenged) communities, the scope for health co-benefits from dietary change may be more important than elsewhere, and provide a different 'point of access' for community agents. Such interventions could also involve local health boards, engaged in more holistic and futures-oriented policy development and delivery via Public Service Boards as mandated by Wales' Future Generations Act

[11] For example, https://como.org.uk/ reports nothing within 15 miles of Treherbert.

(Nesom & MacKillop, 2021). None of this, however, is to minimise the difficulty of moving the dial significantly on diet with community initiatives, which although longstanding and widespread in the West have foundered on the difficulties associated (variously) with the provision of information to the community; reliable and seasonally-even growth of local produce; the oft-reluctance and inability of landowners and farmers to become involved, and the (increasingly important in 2022) equation that means supermarket-provided food, free of the pricing-in of environmental and social externalities is simply cheaper, leaving poorer places behind in dietary change (see Hendry et al, 2018 and Olgethorpe & Heron, 2013 for two of the many relevant papers).

Other Household Spending

The level of community-driven decarbonisation of the last element of household 'carbon guilt' – here a 'grab bag' of expenditure not covered elsewhere – is by its nature hard to assess. Decarbonisation of established communities (such as Treherbert, which indeed only exists due to coal) does not often carbon arising globally from households' consumption locally, and along global supply chains (Boswell *et al* 2012). Exhortations to reduce consumption for environmental reasons, starting with the Club of Rome (Meadows *et al* 1972) and continuing with the decroissance/degrowth movement of today[12] are typically aspatial, or seek to challenge national, international or global structures. The role for communities in a transition away from consumerism – and the impact on carbon – is less understood, although the work in the UK of *Steady State Manchester*[13] is notable here (and see Groves et al 2021; Cherry et al, 2022 for related Welsh examples). As Jones (2022) points out, even in relatively-communitarian Wales, households are simply unused, over generations, to having their household expenditure decisions meddled with, except by the vagaries of markets or government sin-taxes. Attempts, at community level, to engage with residents about the nature and impact of their consumption choices will garner an uncertain response, especially at a time of significant cost-pressures, and where relevant climate and other impacts seem a long way away.

[12] https://www.degrowth.info/en/
[13] https://steadystatemanchester.net

Industry

It is a debatable point whether employment sites located within a community and (here) owned largely outside are part of the carbon responsibility of a 'place'. Residents of small communities typically have (in the UK) very limited control over the scale and scope of employment within their places, outside of, for example, failing to frequent local consumer-oriented businesses, or protesting against particularly unwanted activities or firms. Leaving this conceptual debate aside, the two major employment sites in Treherbert illustrate the industrial decarbonisation agenda. Transport for Wales is fully engaged, investing in the South Wales Metro to electrify the rail, and committed to using (50% local) renewable power[14]. Meanwhile, the Everest window factory manufactures (largely) PVC window frames, at a likely CO2e cost of perhaps around 400kg per frame (Yousef Teenou, 2012). In neither of these cases is the local community a key driver fin climate transition. TfW is more 'local', effectively owned by the Welsh Government and hence with an (indirect) community link via elected representatives. Whilst there is zero effectively community influence over 'big' rail decarbonisation, TfW has recognised the need to engage communities in its development plans – with this extending, potentially, to rail-side supply of community renewable electricity for trains and stations. TfW has also recognised the well-developed nature of community activism and climate awareness in Treherbert, and Welcome to our Woods currently hosts the TfW community liaison officer. For the window manufacturer, Everest, influence is far more tenuous; headquartered in Welwyn Garden City and owned by an investment fund, decisions on products, materials and processes at the Treherbert factory will depend on corporate strategy and market conditions far away from the valley. Coincidentally but illustrative, Everest is in a sector where third sector and government has tried to innovate and replace existing products and approaches in service of climate and local development objectives, and continues to do so, not least in the village[15]. Climate success for Treherbert might then in part imply competition with its largest employer.

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[14] https://businessnewswales.com/transport-for-wales-launches-sustainable-development-plan/
[15] See http://news.bbc.co.uk/1/hi/wales/8003390.stm, https://woodknowledge.wales/home-grown-homes

The Potential for Carbon Capture

The learning from above should be that reducing GHG emissions from households to zero is extremely difficult, and in some cases perhaps impossible. The question then remains what to do about those remaining emissions which it is unrealistic or unaffordable to extinguish. Here, there is an extensive literature about the scale and nature of carbon 'offsets', whereby emitters pay to avoid emissions elsewhere, albeit with significant logistical, audit and moral difficulties (McAfee, 2022) and on carbon sequestration, where GHGs are removed from the atmosphere by either natural or (as yet non-existent and/or tested-at-scale) technological means. Treherbert would seem to be well placed for the former, as a small community surrounded by extensive landscape that residents and the landowner[16] are seeking to mange long-term for multiple, commonly-agreed objectives. Given the primacy of the climate and energy transformation in both public sector and local priorities, the management of the land surrounding Treherbert to contribute to these objectives would appear to be obvious. An analysis of the potential reveals, however, the likely barriers and limitations of local sequestration for such communities.

Firstly (and like almost all land in the UK) Treherbert's landscape is already being used; overwhelmingly for publicly-owned plantation forestry, with an extremely large private windfarm occupying the highest ground. This Vattenfall lease has already, of course, contributed to the decarbonisation of the UK electricity grid, and been appropriately accounted via Renewable Energy Guarantees of Origin and Renewable Obligations Certificates[17], leaving less physical and conceptual space for community renewables. The tree scape, then, is managed for a variety of purposes, including income from timber and (increasingly) recreation and biodiversity. Further constraints on landscape transformation include long term forest resource plans, which are difficult to change, especially within the context of complex (UK and Welsh Government) legislation, and the longstanding culture and habits of foresters (Halofsky *et al* 2018). Add to this the tree diseases, potentially unstable coal-tips, and sheer steepness that

[16] Technically, Natural Resources Wales manages the landscape on behalf of the Welsh Government.
[17] https://business.vattenfall.co.uk/ppas-selling.html

make working the area complex and dangerous and it is clear that the new landscape, even if community co-produced, is very unlikely to prioritise climate quickly, and above all else.

The story is far from wholly negative – for example, the area includes peat bog at Cwm Saerbren which is currently of poor quality, and slated for climate-beneficial re-wetting as part of the joint management plans[18] - with such remediation being an important part of landscape climate sequestration plans more generally. It is likely that the ultimate potential of the landscape to sequester carbon (in comparison to the emissions of local people) will be not insignificant. For example, whilst Lal *et al* (2018) suggest that a best-case example for temperate soils found locally might see 1-2 tonnes of carbon sequestered annually per hectare, more detailed and forest-specific numbers from UK Forest Research are more optimistic, at around 7 tonnes per annum[19]. Whilst this is not a trivial amount, the full 1,000 hectares of land that could reasonably be considered as surrounding Treherbert (see Figure 1) could then sequester around seven thousand tonnes per annum, around 15% of current baseline annual household emissions for the village. These 'savings' are subject to some uncertainty as climate change itself affects the viability and success of relevant species and methods (Grist 2022), and of course would require the removal of the existing trees, and the long-term capture of the embedded carbon[20]. These difficulties and immutable uncertainties indicate the necessary dominance of direct emissions reduction rather than sequestration in any transition plan[21].

Conclusion

In some ways Treherbert might be thought of as a model community for a climate transition that goes beyond the difficult-to-replicate model of the Transition Towns of the past. Challenged in a number of ways yet levering its social capital

[18] The peatlands map of Wales is available at https://smnr-nrw.hub.arcgis.com/apps/d18ef8c74ecc4dc4a0cbf71ab6935ba0/explore
[19] Albeit with very significant variance; see https://cdn.forestresearch.gov.uk/2012/05/fcrp018.pdf page 46.
[20] Or the use of timber products to effectively replace carbon intense fuels or durable products, which is not easy.
[21] The widespread carbon offsetting plans of corporations effectively depend on this balance being very different in the global South of course.

through grassroots community bodies to face up to global and local challenges, to increase climate (and economic) literacy, and to take a more proactive stance in its own future; wresting (or at least gently persuading) back agency from higher spatial scales. None of this however detracts from the sheer difficulties involved in moving communities - and by extension countries - to lifestyles and employment that are genuinely net zero carbon.

Our initial, desk-based estimate of Treherbert's current emissions footprint, albeit crude in some respects, shows a relatively even distribution of emissions across the range of climate change drivers. Every element must be addressed as quickly as feasible (Allen *et al,* 2019) and this will require concerted action by overlapping coalitions of public, third sector and private organisations, working at different spatial scales. Climate interventions will have to be mindful of interactions between different thematic domains, and of course on the feasibility and acceptability of actions within communities like and unlike Treherbert.

Within this broad and challenging context we can identify some emerging learning, relevant to Treherbert and probably beyond. Firstly, we can point to the relative unimportance of commuting emissions; for this around 2% of household emissions here. Thus, whilst all emission sources must be addressed, we cannot expect very significant climate benefits from changes in commuting behaviours (although the benefits would be somewhat greater for places with higher rates of employment, further from large employment centres, or unserved by suitable public transport). For communities like this, where housing is hard to heat, we must be careful of assuming pandemic-related 'working from home' behaviour change is an unalloyed climate benefit; levering such benefits might require instead decentralising employment, for example in local, energy efficient and renewably powered co-working spaces.

A second learning emerges around the role of (local) land in carbon sequestration. Even in the best case, where we assume land can be fully (and quickly) repurposed for mitigation (and isn't already covered in trees and turbines), linking a small, 5,800 population community like Treherbert with a very significant (1,000Ha) parcel of land accounts for only around 15% of current baseline GHGs - and of course such repurposing is far from easy. Whilst carbon offsetting that relies on similar processes might be a superficially attractive accounting and marketing move, the intellectual exercise of extending the Treherbert 'land-people equation' to somewhere like London is stark. Unless the technological development and build-out of carbon capture happens with unprecedented speed (and it probably won't, Singh & Dhar, 2019), we will need a *lot* of land.

Our analysis of Treherbert's GHG footprint brings the significant global challenge of climate transition 'home', to the places people live. Climate change is of course already within this community; in the wind turbines that surround it, in the new diseases in its trees and in the water that is flooding the valley with increasing frequency and damage[22]. Here, we link cause and effect much more concretely at the level of the place, where there are real opportunities to lever community structures to shape interventions to match the urban and surrounding landscapes, to build understanding and acceptance, and to spur changes in attitude and behaviour. After all, to dig out the old adage, you can only manage what you measure.

[22] https://naturalresources.wales/about-us/news-and-events/blog/storm-dennis-one-of-the-most-devastating-storms-to-hit-wales-in-recent-history/?lang=en

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Annex 1 – Data and Methodology

Element	Data Source(s)	Level	Year	Notes
Housing (heat & power)	Knight et al, 2017	Wales & constituent Census Output Areas	2016	Treherbert-specific modelled estimates of annual domestic energy demand & resultant emissions based on building type & age. Note non-domestic building energy emissions captured under *Industry* Full data at http://orca.cf.ac.uk/107222/
Transport (excl commuting)	Department of Transport – Transport Statistics for Great Britain 2021 https://www.gov.uk/government/statistics/transport-statistics-great-britain-2021/transport-statistics-great-britain-2021	GB	2019	Per capita GB transport emissions applied to Treherbert population, amended for income levels based on Büchs & Schnepf (2013) & relevant local household income estimates (see https://statswales.gov.wales/Catalogue/Business-Economy-and-Labour-Market/Regional-Accounts/Household-Income/householdincome-uk-100-by-area-year)
Commuting	England & Wales Census of Population 2011	England & Wales & 2011 wards	2011	Method (mode) of travel to work and distance travelled to work from 2011 Census combined with BEIS 2019 GHG conversion factors for per-passenger km by mode (https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019)
Food & Drink	Rippin *et al* 2021; Reynolds *et al*, 2019; Hoolohan *et al* 2013; Gough *et al* 2011	UK	various	GHG emissions associated with 'typical' UK diets taken from across a range of studies and averaged. Note, Rippin et al find no association between income level and dietary GHG emissions in the UK so no adjustment made.
Other Household Spending	Baiocchi *et al* 2010	UK & socio-economic segments	2004/5	Whilst this paper and data are old, the UK-specificity and reporting of ACORN segments allows tailoring to Treherbert expected expenditure characteristics & consequent CO2 (after excluding spend categories estimated above). There will be likely some over-reporting due to reductions in CO2 intensity of supply since 2004/5 and possible overlap of food & drink expenditure outside the home.
Industry	UK business register and employment survey (BRES) – available from www.nomisweb.co.uk. Input-Output Tables for Wales, 2019 (unpublished)	UK wards (BRES), Wales (Input-Output)	2019	FTE (workplace) employment within Treherbert for 2-digit SIC combined with estimates of GHG per FTE employee for relevant sector in the Wales Input-Output Tables 2019. Note, GHG estimates are currently for 2018, and the modelling does not capture non-UK emissions (nonetheless, this approach was preferred over BEIS GHG by commodity estimates for UK last updated in 2013).