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Doing things differently: Bridging community concerns and energy system modelling with a transdisciplinary approach in rural Ireland

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ABSTRACT

This paper reflects on the experience of co-producing energy strategies on the Dingle peninsula, a rural peripheral region in Ireland's South West. For the past three years, researchers from sociology, community development, and energy engineering have worked in partnership with Ireland's electricity distribution system operator and local non-profit organisations supporting enterprise and community development in the region. This involved coordinating the research with the transdisciplinary partnership established and widespread community consultation (including fifteen community meetings that received roughly 400 attendees) to understand the concerns and priorities of residents. The initial research focus was to incorporate stakeholder preferences into energy scenarios using a simulation modelling tool (Low Emissions Analysis Platform, LEAP). This was revised in favour of support for local development effort to prepare a strategic plan for the area across social, economic, and environmental domains. Widening the scope in this manner posed a serious methodological challenge but was necessary to respond to local needs and foster local impact. The results highlight the imperative of understanding the messy reality within which energy systems operate, and the need to align rural development with climate action policies via authentic engagement. A key contribution from this novel approach is to shine a critical light on the limitations of energy system models. This research serves to highlight the need for co-production/action research efforts that can support real-world transition processes and provide a better understanding of local contexts as an alternative to efforts that would seek to simply improve societal representations within energy system models.

1. Introduction

Traditional techno-centric approaches to energy system planning, generally involve experts determining an 'optimal' solution from a technical perspective and then consulting with communities where the new infrastructure will be built. In such instances, with the goal of participation being to educate the public on the merits of a particular project rather than involving an open democratic process, it runs the risk of becoming a mere *box-ticking exercise* [1]. This inevitably causes tensions as local involvement in the decision-making process is perceived as insufficient or unjust [2–4]. In response, there has been a growing call for collaborative approaches to open up the entire energy planning process [5,6]. While public participation does not guarantee more environmentally sustainable policy or indeed public acceptance, it does increase trust both in the deliberative process and more broadly in the institutions/people. Furthermore, given the difficulty in defining the community ownership of energy, some have suggested that better alternatives lie in emphasising meaningful participation and a fair planning process [7].

Sustainability transitions are highly localised and place-dependent [8]. An essential element of local energy transitions is that they are "*place-based, bottom-up initiatives that are congruent with local identity, values, preferences, and priorities*" ([9], p. 11). Researchers should be respectful of the fact that rural communities experiencing economic stagnation are unlikely to be ready to discuss global existential threats like climate change, and deliberations instead must be grounded on local community development needs rather than primarily seeking out detailed discussions on energy goals [10,11]. The pressing local need to address issues such as demographic imbalance (with limited young families and growing share of aging population), and limited economic opportunities calls for a broader understanding of a what sustainable future means across social, economic and environmental domains.

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There is increasing debate on the prospects of modelling the broader social and political context within which energy systems operate. Li et al. offer a critique of existing quantitative models due to the limited focus on technical feasibility and failure to address socio-political dynamics [12]. They propose three key elements for socio-technical energy transition models to incorporate: techno-economic detail, explicit actor heterogeneity and transition pathway dynamics. Holtz et al. expanded upon this proposal, noting the valuable insights models can provide and outlining a number of avenues for modellers to pursue, in particular stressing the importance of collaboration with 'non-modellers' and stakeholders [13]. McDowall & Geels build on this, listing a number of fundamental and operational challenges to explain why quantitative computer-based models cannot represent complex transition dynamics [14]. They suggest the pursuit of 'plural and diverse' approaches rather than efforts to simplify and integrate societal dynamics. Similarly, Geels et al. point out that properly integrating socio-technical theories and computer-based models is not possible and thus, suggest instead that bridging integrated assessment models, socio-technical transition analysis and practice-based action research may be a more useful way of addressing the needs of policymakers at differing levels (international, national and local) [15]. More recently Trutnevyte et al. propose that building new models or modifying existing models is needed in order to merge socio-technical theories and modelling approaches [16]. While Hirt et al. in a review of progress to date linking energy and climate models with socio-technical theories, found '*an apparent lack of concrete recommendations for climate and energy solutions*', and thus call for the exploration of transdisciplinary approaches to create more practical and actionable solutions ([17], p. 175).

The need for energy system modellers to pursue participatory approaches is reflective of a growing trend throughout sustainability science that calls for more societally engaged and action-orientated research [18–22]. Within this, co-creation and co-production are most commonly seen as a participatory governance process that can support key societal goals in an inclusive manner [23]. Recent literature reviews have found a very limited number of existing examples of co-production approaches to energy system modelling and planning. McGookin et al. reviewing examples of participatory methods in energy system modelling and planning found that a significant number of studies had involved a single 'extractive' interaction with stakeholders, with only ten out of fifty-three studies involving a collaborative approach [24]. Likewise, Galende-Sánchez & Sorman found that participation remains very focused on top-down approaches, where citizens are increasingly consulted on climate and energy policy issues but in most of the cases cannot affect the outcomes [25].

There are nevertheless some useful examples of co-production approaches to energy system modelling and planning from which to draw on [24]. Trutnevyte et al. worked with the local mayor in a Swiss rural municipality to setup a steering committee that oversaw the development of an energy strategy for 2035, focusing on heat and electricity sectors [26]. Schmid et al. exploring scenarios for Germany's electricity in 2050 established a project team consisting of researchers and NGO representatives in order to ensure the quantitative energy system analysis was underpinned by socio-political expertise [27]. Zivkovic et al. likewise focus on a single sector, assessing heating scenarios for a Serbian city [28]. Heaslip & Fahy take a more comprehensive view of the energy transition with an island case study, exploring topics like energy access, affordability, and security [29]. However, also neglect the transport sector. Dubinsky et al. formed a community advisory board "*as an open forum for board members to provide input and share relevant current happenings in the region*" and take a broader look at sustainability by covering both greenhouse gas emissions and water use ([30], p. 84).

Drawing on previous suggestions to bridge rather than merge analytical approaches [15,16,31,32], this paper asks*: to what extent is it possible to bring the (qualitative) insights from the stakeholder engagement into (quantitative) energy system modelling tools?* Stemming from this, the paper also offers reflections on: what the participatory process tells us about energy system models? And what challenges are associated with working in this manner?

The investigation involves four important layers. Firstly, the authors adopt a co-production approach, involving extensive stakeholder engagement to design and conduct the research collaboratively with local representatives, and to ensure that the energy system modelling is informed by local insights. Secondly, at the heart of the investigation is the development of energy scenarios using a simulation modelling tool (LEAP). The paper develops two central scenarios, similar to the work of Meyer et al. [11], and a number of variants from the central scenarios. One central scenario is a reference scenario, which represents a return to previous trends following the COVID-19 pandemic and the second is a 'build forward better' scenario following the COVID-19 pandemic. Thirdly, respecting the needs of local partners and the community, the public engagement carried out did not simply explore perceptions of climate change and potential energy system alternatives as had originally been planned. Rather it entailed a broader investigation into the opportunities for a desirable future incorporating social, economic, and environmental concerns. Finally, we offer critical reflections on the co-production approach taken, what learnings it adds to the energy system modelling process and the prospect of improving societal representations within modelling tools.

2. Bridging participatory action research and energy system modelling

The following sections introduce the transdisciplinary partnership established, different ways in which the research consulted with the local community, the process for modelling future energy scenarios and linkages between them. A distinction is made between co-production and participatory action research as follows: co-production refers to the overarching collaboration with local partners, while within this, the participatory action research elements are specific engagements that sought to build an understanding of the local context while also supporting development needs.

2.1. *Overarching transdisciplinary partnership: Dingle Peninsula 2030*

The engagement of non-academic stakeholders in research through approaches like community-based participatory research or other action-orientated approaches is not a new practice [33–36]. However, transdisciplinarity as an emerging trend in sustainability science has appeared with a number of different interpretations [35,37]. This is not a topic for discussion within the present body of work, but it is important to outline our position within the field. On one level, transdisciplinarity may be considered as involving open interdisciplinary collaboration (undertaken with the necessary prerequisite of "disciplinary humility" [38] seeking new knowledge through participatory methods involving stakeholders from outside academia [35]. It is important however, as noted in the Introduction, to distinguish between extractive participatory methods with limited dialogue or shared learnings and the pursuit of co-production approaches. As set out by Norström et al., there are four key components to knowledge co-production [21].

1. It is *context-based*, as a process within a particular place or issue. The investigation of complex societal challenges in local contexts helps to develop an understanding of sustainability transitions, which can foster meaningful action [39,40].
2. It recognises the value of *different forms of knowledge*. As a matter of best practice, a vital component of a transdisciplinary research project is the establishment of a committee comprised of interdisciplinary researchers and representatives of other stakeholder groups [41].
3. It is *action-oriented*, seeking to solve real-world problems. These approaches have emerged in a large part due to the urgency of

contemporary sustainability challenges, and demand for actionable solutions [20,42,43].
4. It is highly *interactive*. Co-production requires an iterative engagement over the full knowledge creation process, beginning by collaboratively framing and designing the research, working together to conduct the research, and jointly benefitting from the outcomes [30,44].

This paper is based on the experience of an ongoing multi-stakeholder collaboration taking place on the Dingle Peninsula in Ireland's South West [45]. The two central research strands involve analysis of the multi-stakeholder approach to the socio-technical transition (see Boyle et al. [46]) and investigation into the co-production of energy scenarios detailed in this paper. This approach is outlined here with regard the four pillars of knowledge co-production [21].

1. The work has been conducted as part of an ongoing project "Dingle Peninsula 2030", which is a regional sustainability transition project. It sets the ambition that the area may be an exemplar to demonstrate how the transition to a low carbon future paired with community development objectives can improve rural sustainability and resilience.
2. The research team setup and coordinates a collaborative governance committee that meets regularly (generally monthly) to oversee activities in the area, and facilitate input into the research design and implementation process [47,48].
3. The research has been conducted in collaboration with the local representatives to support projects emerging in the area. In the context of this paper, there have been two key contributions.
   a. The lead author was a member of the steering committee setup to oversee the development of an initial estimate of the area's energy-related CO_2 emissions, provided the necessary analysis [49], and co-produced a report on it with local representatives [50].
   b. The community planning process that the lead author was involved with, was not only co-ordinated in partnership with local representatives but also co-funded by the research centre.
4. All research activities were designed and delivered in partnership with the local representatives of the governance committee. As outlined in Section 2.2, there was an extensive community engagement process.

2.2. Participatory action research approach to community engagement

A core component of the approach taken was that it was flexible and great effort was made to design the research process with our local partners, evolving along with activities on the ground. Attention is given here to the contrast between the original plan and adopted approach, for a description of key actors, how they were involved, and the community engagement process see Appendix A.1.

Following the review outlined in McGookin et al., the importance of a three-stage engagement process had been identified, consisting of: a scenario visioning exercise, discussion on pathway or technology preferences and finally an evaluation/feedback session on the energy system modelling results [24]. It was expected that the 'Sustainable Energy Community' group formed by our local partners to coordinate energy efficiency and renewable energy projects would see this long-term planning exercise as the logical next step having determined current energy-related CO_2 [49]. A plan was drafted for how to structure these series of discussions on model inputs and outputs, which would ensure a clear linkage between the stakeholder inputs and energy system model. However, it quickly became evident that this approach was not well aligned with the interest of our local partners.

In collaboratively agreeing a community engagement process it became clear that the framing of discussions would need to be wider than just desirable climate and energy futures. The research became part of a broader effort lead by the local development organisation (concerned with establishing a baseline against which socio-economic and demographic trends could be assessed [51]) to align with the community's needs. This was seen as important: to avoid '*preaching to the converted*' and reach a more representative group, and also to get a more comprehensive understanding of the problem(s). There were two rounds of community meetings, with a total of 15 meetings across the 8 parishes that make up the region. During which participants were essentially given a blank page to outline their concerns and priorities. This posed a serious methodological challenge for the modelling (Section 3.2) but was a required trade-off to stay true to the participatory process (Sections 4.2 & 4.3).

A brief summary of the community engagements is provided in Table 1. It had four elements. Firstly, the initial scoping exercise with university students from the case study area. This involved several informal meetings before bringing a group of thirteen together for a workshop discussion. During the discussion a series of questions were posed before grouping the answers under common themes, see Appendix A.2. Secondly, there was a much broader community engagement process in the region as outlined in the previous paragraph. Thirdly, following the onset of the pandemic, an additional online virtual workshop was held in June 2020 that sought to 're-imagine' how the region could 'build forward better' after the pandemic co-organised with the enterprise development organisation, Mol Téic (Dingle Creativity and Innovation Hub) [52]. Finally, a session was held with Corca Dhuibhne Community Energy Group to discuss the energy scenarios developed, initial modelling results and get feedback on the analysis.

2.3. Energy system modelling using LEAP

The energy system was modelled using the LEAP (Low Emission Analysis Platform) software, which is a simulation tool for exploring energy scenarios [53]. As outlined by Nilsson et al., LEAP was favoured over an optimization model as it relies on user input to define the energy system configuration as opposed to a least-cost solution [31]. This facilitates the exploration of scenarios based on questions and proposals raised during stakeholder engagements.

A wide range of measures were modelled in each sector to assess possible pathways. These have been collated into five representative mitigation scenarios based on two potential reference scenarios; a return to pre-COVID-19 pandemic trends that would represent 'stagnation'

Table 1
Stakeholder groups involved in engagement process and their input into the energy system model.

Stakeholder Groups	No.	Description	Input into energy scenarios
Students from the area studying in University College Cork	13	Third level students in 3rd/4th year of study coming from a wide range of subject areas	Initial scoping exercise to capture key issues facing the area and get input on the proposed research process
Community meeting attendees	398	Residents from the area, generally representing older age groups	Highlighted key issues facing the area, priorities for future development and additional measures to explore (such as active/public travel, renewable energy microgeneration)
Re-imagine workshop attendees	28	Selected to represent key groups: farming, tourism, hospitality, young people, ongoing sustainability initiatives and social services	Framing of the build forward better scenarios and additional measures to be explored (such as active/public travel, renewable energy microgeneration)
Corca Dhuibhne Community Energy Group	8	Voluntary group exploring opportunities to establish an energy co-operative in the area	Feedback session held to discuss initial results and model inputs

Table 2
Summary of energy system scenarios modelled.

Scenarios	Description
REF	Business as usual reference scenario with COVID-19 impact in 2020/21 and then stagnation out to 2030
REFPOL1	Downscaling national 2030 targets for key measures like electric vehicles and home retrofitting based on the 2019 Climate Action Plan [54]
REFPOL2	More carefully planning the targets from previous scenario (REFPOL1), e.g. targeting homes with the lowest energy efficiency
REFCOPROD	Additional measures based on stakeholder inputs
BFB	COVID-19 impact in 2020/21 followed by a period of growth out to 2030
BFBPOL2	Mitigation measures from REFPOL2
BFBCOPROD	Mitigation measures from REFCOPROD, along with additional considerations to deal with the rebound in emissions in post-pandemic recovery

versus a "build forward better" scenario. Table 2 provides a brief overview of the scenarios modelled, for a more detailed outline see Appendix B.1. In addition, the potential resource from a variety of renewable energy sources was estimated, these are summarized in Appendix B.2.

2.4. Relationship between stakeholder inputs and energy system model

As further outlined in Section 3.2, the findings from the community engagement provided some elements of the scenarios (see in particular Table 4). How the local perspective was represented in LEAP was discussed a number of times with the local partners and during a feedback session with the Corca Dhuibhne community energy group. This is an important part of the bridging process, as a means to verify the translation of stakeholder inputs into the energy system model. For example, discussing what share of holiday homes became permanently occupied during the COVID-19 lockdown periods or what share of farm sheds should be covered in solar PV panels. However, it should be noted that a detailed discussion of these model parameters was generally not of interest so much of the decision-making remained in the hands of the research team.

Recognising the models limited ability to capture the broader societal picture, a useful means of placing the energy scenarios into the local context is to consider the societal capacity for implementing them. As Pedde et al. highlight in developing a framework to understand the implications of societal capacity across the five global shared socio-economic pathways (SSPs), social equality is as important as technological development in achieving the 1.5 °C target [55]. Similarly, in this study, we explore on a local scale the implications of twelve wellbeing indicators identified. The purpose of this exercise is to complement the energy system modelling insights with an in-depth understanding of the context within which the proposed transformations are to take place. This can identify important co-benefits, trade-offs and areas of potential difficulty, and thus more informed policy interventions. Following the definition of Dodge et al., wellbeing here is seen as "*the balance point between an individual's resource pool and the challenges faced*" ([56], p. 230). As outlined by La Placa et al*.*, framing wellbeing beyound personal health and within broader societal contexts "*reflects the conceptual complexity of 'wellbeing' and highlights its dependency upon a range of social, economic and environmental forces*" ([57], p. 116). While it is recognised that there has much debate on the use of the term wellbeing and its definition, during the community engagement process it emerged as a useful concept to pull together a range of complex and interconnected issues.

3. Results

3.1. Community engagement findings

During both the initial student engagement and broader community consultation, a lot of the key concerns centred around the risk overtourism posed to the area and limited opportunity for young people outside of this and the agriculture/fishing sectors. A summary of the findings from the student workshop is provided in Appendix A.2, while the full set of notes recorded during the two rounds of the community meetings have been published online [58,59], along with a summary learning brief that was co-produced with local partners [60]. The publishing of the raw data and sharing with those who attended was seen as an important element of transparency as it ensures the findings remain useful to the community after the research project has finished. Table 3 provides an overview of the most commonly stated challenges and potential ways to address them. This list of cross-cutting issues is useful for pulling together groups from the area. However, it must be acknowledged that those listed are by no means exhaustive. There was a very broad range of issues discussed, which were often unique to some parts of the peninsula. While a lot of the issues raised were not related to energy, it helps us to understand the priorities of the community and what sustainability means to them. During the 'Re-Imagine Dingle Peninsula' workshop seven working groups were formed around key projects, which included: a sustainable transport network, capitalizing on a move to remote work post-COVID, developing mixed housing complexes for young and old families, and green spaces. The remainder of this section focus on the findings from the 15 community meetings held.

Table 3
Summary of common issues and projects discussed during the community meetings held in November 2019 and February 2020.

Common Issues, 1st Round, November 2019	Proposed Interventions, 2nd Round, February 2020
• Caring for the aging population; access to shops, health services, etc. • Supporting community development and the work of community/voluntary groups • The expansion of facilities and amenities for young people • Ensuring farming is competitive and that there are better linkages between farming and tourism • Strengthening community relationships and resilience • Protecting the magnificent culture, language, heritage, and landscape of the area • Reduce reliance on imported fossil fuels in favour of locally available renewables	• Improved public transport and interconnectivity servicing all areas of the peninsula • Prioritize housing for full-time residents, not holiday homes • Development of mixed/sheltered housing complexes to cater for young and old in town centres • Address issues with sewage/wastewater treatment that are limiting ability to build new houses • Large number of vacant homes that could be renovated to newest energy standard • Supporting active modes of travel with improved paths/walkways as well as cycling infrastructure • Develop year-round economic activity not just for the tourist season • Provide indoor and outdoor community areas • Promote the growth of native woodlands and rewilded areas • Installation of solar PV on all available rooftops: community centres, businesses, farm sheds and homes

The community meeting discussions provide two important considerations. Firstly, worrying about an existential threat like climate change is a privilege that is not afforded to rural communities facing grave demographic, social and economic challenges. Secondly, social, economic and environmental (un)sustainability issues are exasperated by the fact that regional, county and indeed local development plans to do not adequately reflect the concerns and priorities of the community [60].

There was a lot of frustration at the limited access to housing driven by the National Planning Framework's priority of 'compact growth' [61], which significantly restricts the building of any new one-off houses outside of village and town centres. Under Ireland's very centralised governance system, the local authority has a statutory obligation to implement this objective and extremely limited autonomy to address local housing concerns. However, there was a strong perception in the community meetings that the local authority is to blame. The role of the local authority is poorly understood, and they are seen to be responsible as the ones who designate housing zones through forward planning and the processing (or rejecting) of planning applications. There were several accounts of younger families seeking to build on their parent's land but being refused planning permission. This is preventing the intergenerational mixing that traditionally provided childcare and support for the elderly.

The purpose of the 'compact growth' objective is to address the connectivity challenges posed by Ireland's very dispersed population, which has resulted in a heavy dependence on private car travel. As previously highlighted by Carroll et al., much of rural Ireland suffers from forced car ownership due to the limited availability of public transport alternatives [62]. This issue was prominent in the community meeting discussions with a number of concerns raised; measures like a carbon tax will be overly punitive on rural people who have no option but to drive, elderly people have difficulty accessing vital services and businesses in town centres suffer because of the poor connectivity. The existing public transport service is extremely limited. For example, community 5 (see Fig. 1 below) has just a single service on a Friday connecting to Tralee, the county capital, which is just outside where the peninsula meets the mainland.

The wellbeing indicators seen in Fig. 1 are a useful way to reflect on the issues raised during the community engagement process. It provides a comparison of the eight communities that make up the case study region against county and national values across key drivers of energy demand (car ownership, housing quality), demographic profile (share of young families, over 65 s, etc.) and other socio-economic statistics (gross median income, broadband access). The values have been colour scaled to highlight those with the largest deviation in red from the national average which is green. It should be noted that the national or county averages are of course not necessarily desirable figures. However, a comparison in this manner nonetheless helps to highlight issues of concern by assessing how the area is faring relative to the rest of the country and county. The majority of values are based on the Census of Population of Ireland taken in 2016, as that is the most recent currently available [63].

The two most peripheral communities (2 & 5) show the furthest deviation from the national average. This was reflected in discussions during the community meetings, in which there was frustration about those not on the development line (see N86 road in green on Fig. 1) between the mainland and the largest town in the area (Community 6) being left behind. There is a compounding of issues in these communities. As the communities with the highest share of seasonally occupied holiday homes (up to 40% of houses), they thus have the lowest

Wellbeing indicators	Community								Region	County	Ireland
	1	2	3	4	5	6	7	8			
share of low energy rated homes	18%	19%	15%	19%	23%	16%	21%	19%	18%	14%	12%
solid fuel share of primary heating	8%	8%	7%	8%	9%	7%	9%	8%	8%	7%	6%
cars per capita	0.57	0.57	0.60	0.53	0.75	0.45	0.63	0.60	0.55	0.52	0.48
share of households with broadband	51%	51%	63%	59%	60%	57%	49%	56%	51%	61%	71%
gross median income per household	74%	70%	97%	76%	85%	78%	80%	85%	80%	83%	100%
share of permanently occupied homes	68%	51%	77%	59%	48%	62%	66%	72%	62%	74%	85%
growth in homes from 2011 - 2019	4%	4%	2%	2%	4%	4%	6%	3%	4%	5%	6%
change in population 2006 - 2016	8%	-2%	-3%	9%	-11%	5%	-7%	4%	2%	6%	12%
single occupancy households	31%	35%	23%	30%	34%	34%	31%	24%	31%	28%	24%
share of population over 65	17%	18%	18%	19%	17%	15%	15%	16%	17%	15%	12%
share of population between 50 - 65	19%	27%	24%	19%	32%	22%	24%	21%	23%	20%	17%
share of young family households	27%	22%	21%	28%	17%	26%	27%	26%	25%	26%	31%

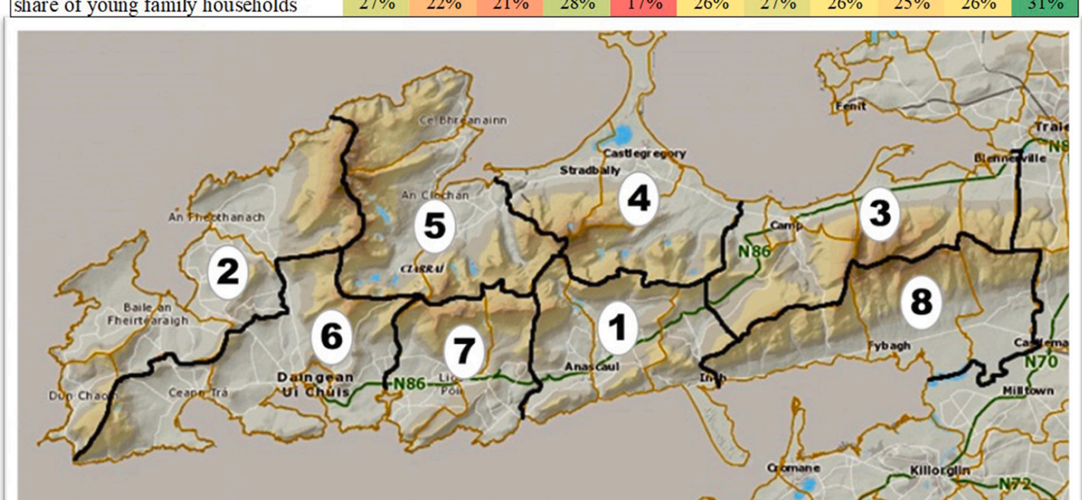


Fig. 1. Wellbeing indicators identified in the 8 communities that make up the case study region compared to county and national figures (CSO data 2016), along with a map indicating the location of the communities.

availability of homes at around only 50% of the housing stock. The absence of young families is particularly striking in community 5 at 17% of households compared to 31% nationally. In line with this, these communities have high shares of aging population and people living alone while also having the worst quality housing (from an energy perspective). Unfortunately, it is not possible to determine the overlap between these two sets of data, but it is likely quite high. This issue was a prominent topic in the community meetings, with great concern that the most vulnerable in the community may be experiencing energy poverty.

3.2. Translation of community input into energy scenarios

As introduced in Sections 2.2 & 2.4, a key methodological challenge in the present study was the link between the findings from community engagements (Section 3.1) and the energy system model developed (Section 3.3). There were three common issues: areas of interest to the community neglected by national policy (e.g. rooftop solar PV, public transport, bioenergy), concerns of the community that couldn't be represented in the model (e.g. vacant homes, bus tours) and instances where there is tension between national policy and local concerns (e.g. compact growth, tourism). These are summarized with reference to key issues in Table 4.

The fact that the scenarios informed by local interests achieve the lowest emissions savings (Section 3.3) is not so much reflective of the community's ambition as it is the misalignment between national policy and community interests. The measures based on community input are represented as additional to current policy, which lacks coverage of them. With respect to renewable energy, Irish policy to date has been strongly focused on large-scale developments (as is the case internationally [64]) and in particular wind energy, while generally neglecting the smaller/micro-scale technologies that were found to be of most interest to the community: rooftop solar PV, small-scale hydro and bioenergy. In transport, public/active travel were seen to represent far more effective interventions than the electrification of private cars, which until recently was the central policy priority.

A significant issue raised throughout the community meetings was the need to reduce the number of seasonally occupied holiday homes and provide houses for young families looking to settle in the area. In addition, during the 'Re-imagine Dingle Peninsula' workshop one of the central themes was how the region might capitalize on a move to remote work post-COVID. These are the narratives that the 'build forward better' scenarios attempt to represent. A key driver for understanding the scenarios is the population projections. In the reference scenarios, between 2019 and 2030 the population would grow at an average annual

Table 4
Comparison of national policy, local perspectives and their representation in LEAP for a number of key topics.

Topic	National policy	Local perspectives	Representation in LEAP
Residential heating	Poorly defined retrofit and heat pump targets	• Concern about the amount of overlap between ~30% living alone, ~20% over 65 and ~ 20% lowest energy rated houses • Individual investments too high even with grant support • Lack of contractors available locally	Scenarios explored the impact of retrofitting lowest rated homes as opposed to an even share across dwelling types
Private travel	• Focus on private cars switching to electric vehicles • Active/public transport neglected, particularly in rural areas	• Most people rely on second-hand car market • Concerned about range and access to chargers in dispersed rural area • Lifecycle impact of EVs questioned • Buses a vital service for aging population, and keeping small town businesses open • Active modes important for health, particularly in younger population • Better infrastructure can support more sustainable tourism model	Scenarios explored how increases in active and public transport may reduce private car demand
Renewable energy	• Focus on wind and solar • Heat and transport options other than electrification neglected • Favours large-scale developments • Limited supports available for small/ micro-generation	• Significant interest in microgeneration, and in particular rooftop solar PV • Tension between need to reduce reliance on imported fossil fuels and impact of large developments on landscape • Bioenergy of great interest: 1) native woodlands 2) developing local circular economy	~10% renewables by 2030 • Large uptake of solar PV on households, farm sheds, schools, etc. • Native woodland crop developed for secondary home heating • Small scale anaerobic digestion plant provides biomethane resource to replace LPG
Holiday homes	No clear policies in place	• Some communities ghost towns in winter • Extremely limited long-term lets available	Within BFB scenarios: • Having been occupied during pandemic, 25% of holiday homes become permanently occupied by 2030 • No new builds become holiday homes
Vacant homes	Current policies are having limited impact	Frustration at high vacancy rates when young families can't find a home	None
Demographic imbalance	Compact growth places strong emphasis on urbanisation, essentially bans the building of new one-off houses	• Serious concerns about people's ability to live in remote areas • Large number (~30%) single occupancy households	Build forward better population increase based on current demographic makeup. However, uncertain what age groups this would involve.
Tourism	Strongly promoted as a key economic sector, no clear policies to manage local impacts	• Needs to be more carefully managed, important opportunity but also a serious threat • Season limited to 6 months of the year, which is not viable for businesses • Large number (~50/day in summer peak) of daily bus tours coming from outside the area provide very little revenue locally while causing traffic issues and poor air quality	• Majority of businesses assumed closed in the winter • Within BFB scenarios it is assumed that the share staying open year-round grows • Tour buses not included in the transport sector, and air quality impact not considered

rate of 0.54%, around half the national average of around 1% [65], and similar to the previous 0.51% average annual growth seen between 2002 and 2016 [63]. During the period from 2002 to 2016, the region's population grew by 7% compared to a national average of 22% [63] and county-wide growth of 12% [63]. In the 'build forward better' scenario with 25% home holiday homes becoming permanently occupied, the population growth rate experienced in the region would be double that in the reference scenario at around 14% between 2019 and 2030, which would put the region back in line with county and national projections for that period. As noted in Section 2.4, key parameters like these were discussed with local partners but the feedback received was very limited.

Other issues of importance to the community proved difficulty to represent in LEAP. The seasonality of businesses was possible to account for thanks to a previous building survey conducted (Appendix B). However, the impact of tour buses that are a growing concern was not included. New builds within the model could be said to come from vacant homes but this is of limited relevance to the energy scenarios. In addition, there are of course a wide range of issues across culture, heritage, social services and wellbeing that are of vital significance to the community, which cannot be captured in an energy system model.

3.3. Energy scenarios

3.3.1. Reference scenarios modelled

To get an overview of the decarbonisation challenge, Fig. 2 shows the energy-related CO_2 emissions by sector in the reference scenario modelled for 2010–2030, which includes a COVID-19 impact in 2020/21 and then returns to pre-pandemic trends from 2022 onward. The breakdown per sector in the second reference scenario, build forward better, is essentially the same so it is simply shown as the projected increase in CO_2 emissions. Assuming that key drivers of per capita CO_2 emissions such as the rate of car ownership (0.55/person) and household occupancy (2.7 people/house) stay constant, then the total energy-related CO_2 emissions associated with such a rebound are projected to be 8% higher by 2030. There is a clear tension here between ambitions to reduce emissions and community revival.

The two key sources of emissions across both scenarios are private cars and households, which account for the majority of energy-related CO_2 emissions in 2030 at about 65%. As previously outlined in McGookin et al. [49], this is driven by the sparsely populated and isolated nature of the region, which has a population density of about one fifth the European average. There is a noticeable decrease in historical emissions from 2010 to 2019 due to the significant fall in the electricity grid's CO_2 intensity, which nearly halved from 550 gCO2/kWh in 2010 down to 324 gCO2/kWh by 2019 [66]. Otherwise, CO_2 emissions from fossil fuels are projected to remain stagnant over the period.

3.3.2. Energy related CO_2 emissions by sector and fuel in the scenarios modelled

As outlined in Section 2.2, a range of measures were explored in each sector for the period 2020–2030. These were primarily based on national targets for key issues like retrofitting homes, installing heat pumps, or electric vehicle uptake, as well as additional measures emerging from engagements with local stakeholders. Given the significance of transport and residential CO_2 emissions highlighted in Fig. 2, particular focus was given to those sectors. Downscaling the national policy objectives in this manner brings up a couple of interesting insights. Firstly, the scale of the challenge is laid bare when dealing with such a small rural area. And secondly, while high-level ambition like retrofitting 450,00 homes by 2030 is important, the pathway to actually delivering it requires careful consideration.

Fig. 3 gives a breakdown of the energy related CO_2 in 2030 compared to a 2018 reference year for the seven scenarios outlined in Table 2 by sector in the top half and by fuel share in the bottom half. The choice of 2018 as a reference year is based on the recent (enacted July 2021) national target of a 51% reduction in greenhouse gas emissions by 2030 compared to 2018 levels or 7% per annum between 2021 and 2030 [67]. It should be noted that this is essential double what the national target has been at the time of the community engagements and initial stages of the energy system model development, which was a 30% reduction by 2030 relative to 2005 or roughly 3.5% per annum [54]. It is striking that even the highly ambitious COPROD scenarios modelled for the case

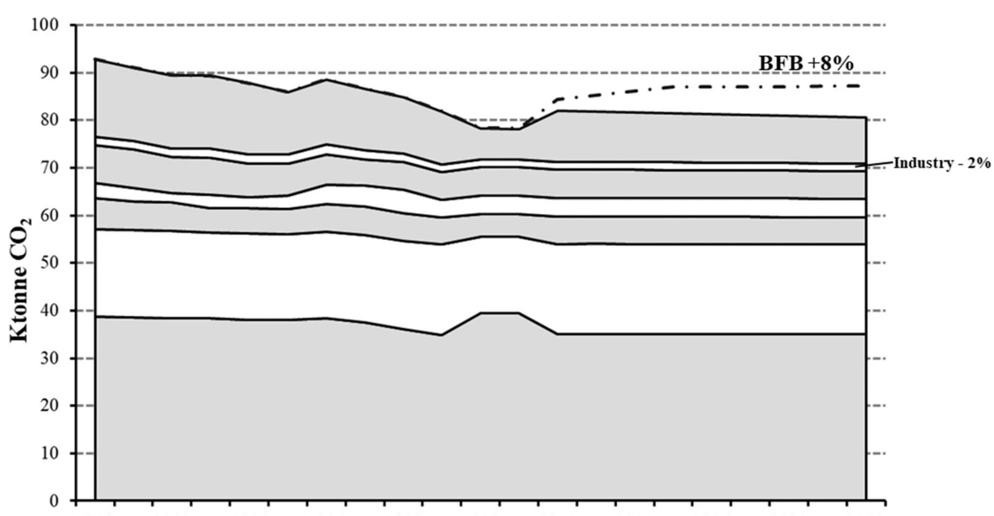


Fig. 2. Dingle Peninsula energy related CO_2 emissions by sector in the reference scenario 2010–2030 and projected increase in the build forward better (BFB) scenario.

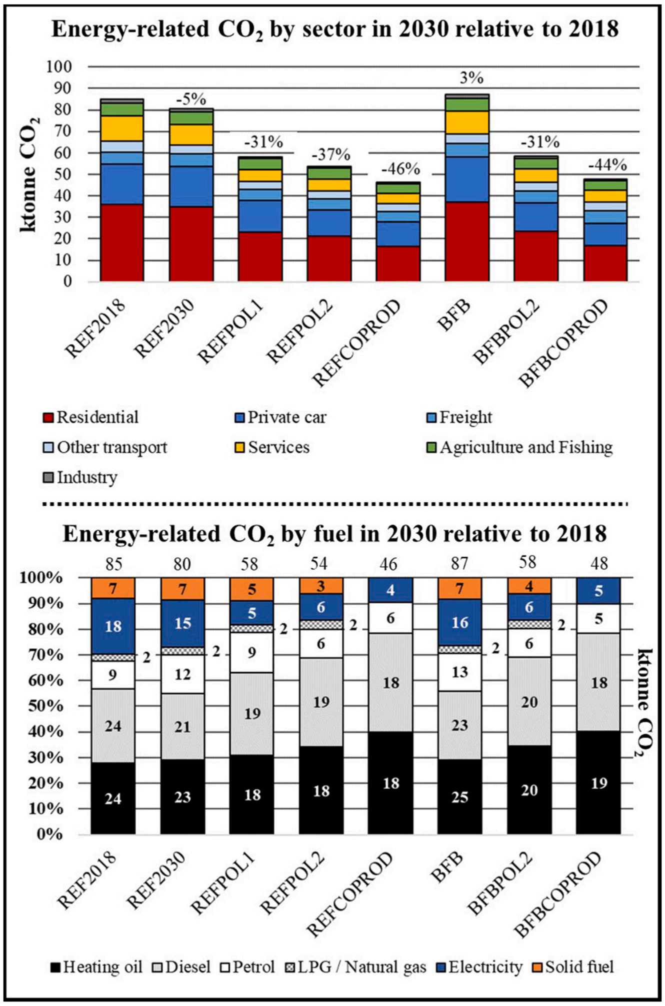


Fig. 3. Energy related CO2 emissions on the Dingle Peninsula by sector (top) and by fuel (bottom) for the end year 2030 in the eight scenarios modelled compared to reference year 2018.

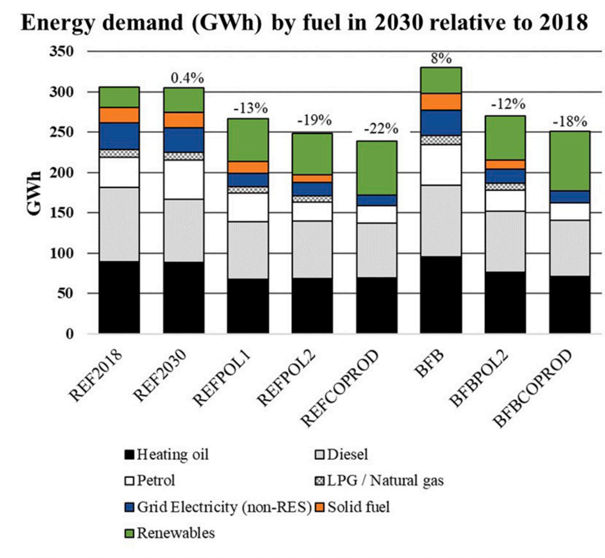
study region fall short of the new target (Fig. 3).

In the residential sector, targeting low rated homes brings significant savings compared to an even spread across the housing stock. While the suggestion to increase the targeted energy efficiency from a B2 to A rated, which was seen as important to avoid a lock-in of B rated homes unlikely to upgrade to A, had little impact as with the installation of heat pumps the majority of the savings occur in electricity, which is expected to have very low CO_2 emission intensity by 2030. Moving onto the transport sector, and in particular private car travel. The BFBCOPROD was significantly below BFBPOL2 in a large part due to efforts to reduce car dependence. With almost 50% of workers commuting off the Peninsula for work, the potential reduction associated with working from home is quite significant.

Looking at the impact of each scenario on ktonne CO_2 by fuel source in 2030 highlights how key sources of emissions are dealt with or remain. Bioenergy in the form of biomass and biomethane can replace solid fuel and LPG/natural gas in the COPROD scenarios. While the CAP2 scenarios essentially eliminate solid fuel use in primary heating, the COPROD scenarios importantly also eliminate it in secondary heating. At present even in the highest rated homes (A/B), solid fuel is very common in secondary heating at 55–65% of fuel share. The petrol emissions also fall significantly in the higher electrified scenarios (CAP2/COPROD) as small petrol engines or petrol hybrids are projected to be replaced rather than larger diesel engines. Diesel and heating oil continue to dominate energy supply and are the largest sources of associated CO_2 emissions in all scenarios. The heavy reliance on imported oil products remains a key concern, ranging from 60% to 75% of energy demand by 2030. This is in a large part due to the limited impact on diesel vehicles in private car travel, and also the lack of any interventions for heavy goods vehicles, tractors or fishing boats.

Table 5
Overview of the renewable energy sources considered for the case study region.

Source	Identified resource	Chosen annual output
Solar PV	4 MW solar farm	3.9 GWh
	4.5 MW rooftop Solar PV	4.4 GWh
Wind energy	3 × 4 MW turbines	29.4 GWh
	80 × 5 kW pole-mounted microturbines	1.05 GWh
Small-scale hydro	530 kW from 6 turbines ranging from 30 to 180 kW	2.4 GWh
Bioenergy	Biomass - 1000 ha native forestry	8.2 GWh
	Anaerobic digestion of grass and food waste	10 GWh



	Reference					Build Forward Better		
	REF 2018	REF 2030	POL1	POL2	CO PROD	BFB	POL2	CO PROD
RES contribution	8%	10%	20%	21%	28%	10%	20%	30%
Local RES contribution	0%	0.2%	0.2%	0.2%	11%	0.1%	0.2%	12%
Electrification	16%	17%	21%	22%	21%	16%	22%	23%

Fig. 4. Energy demand by fuel on the Dingle Peninsula for the end year (2030) of the seven scenarios modelled compared to base year (2018).

3.3.3. Renewable energy contribution

An overview of the renewable energy technologies considered is provided in Table 5.

During discussions with both representative organisations and residents, the ambition of being 'energy independent' was seen as a strong unifying vision. However, the reality of such a dramatic transformation is challenging. The prospective renewable energy sources were identified through a process of elimination, see Table A.2.4 in Appendix A. There were two recurring difficulties. Firstly, the significant preference for small/micro-scale developments over larger projects despite widespread agreement that reducing energy imports should be a priority. And secondly, at present there is a lack of support for renewable energy developments in the region within the local authority planning department. As a result, the contribution of local renewable sources is expected to be limited.

Fig. 4 provides an overview of the energy demand by fuel for each of the scenarios modelled, comparing the end year (2030) to the base year of 2018. The local renewable energy share is essentially zero, except in the COPROD scenarios when it is expected to be roughly 11% of energy demand by 2030. Interestingly, the local renewable energy sources would account for just under 40% of renewable energy. The national blending of biofuels in transport fuels may contribute around 10 GWh of renewable energy, which is equivalent to the proposed local anaerobic digestion plant or Solar PV developments. This was seen as an effective action in the community meeting as it doesn't require any individual action or investment to switch to new technologies. However, could be criticised as failing to represent the necessary transition.

4. Discussion

4.1. What did the co-production approach tell us about the energy scenarios?

The most valuable learning from the co-production approach is the differences between the *messiness* of the real-world compared the simplicity of the energy system modelled world. The community engagement process was intentionally open to the broad range of concerns people have, which posed a methodological challenge (see Section 4.2) but must be acknowledged as an essential starting point to have an honest conversation about the future. In this case study, taking a purely technical perspective would omit consideration of the serious societal capacity issues outlined in Section 3.1. This context is crucial to identify barriers and develop an understanding of how to implement the necessary measures. For example, looking at housing, the energy system model clearly shows that we need to address the poorest quality houses. However, it is only by looking at broader picture and discussing it with local stakeholders that we can understand who lives in these homes and what sort of policy interventions are needed.

On from this, a key element is the identification of co-benefits. When energy/climate policies are aligned with community development needs, then climate action presents a great opportunity to address some of the inequities in society such as the growing gap between rural and urban populations seen here. The provision of public transport is both an effective way to reduce CO_2 emissions, while also providing an essential social service. Active modes offer health benefits, improved air quality and, important in this case study region, infrastructure for sustainable tourism. Similarly, dealing with the highest emitting homes and ensuring the aging population has appropriate housing can be closely aligned goals.

The benefits of this alignment between community development and climate action are clear but realising them will require more careful policy planning. As illustrated in Section 3.2, the areas interest to the community (solar PV, public/active transport, bioenergy) have been neglected by national policy to date. This means opportunities for community participation in climate action are being missed. On from this, there is the delivery of services. With regards housing, given the likely overlap between poorly insulated homes reliant on solid fuel and an elderly population living alone (outlined in Section 3.1.), managing the necessary disruption to improve the energy performance of these homes will require a careful intervention.

As demonstrated by the results in Section 3.3.2, achieving Ireland's GHG emission reduction target for 2030 will require a dramatic and rapid change to our society. The findings of this study highlight that in order to ensure this is done effectively through a fair and just manner, new more collaborative forms of decision-making are needed throughout the policy process to bring together a diversity of stakeholder views. In addition, it has demonstrated a need to treat climate action as a social issue. When dealt with as such, it may tap into Ireland's rich history of area-based community development for the common good [68,69], but if not, then it risks becoming an increasingly divisive issue (Section 3.1).

4.2. Reflections on the co-production approach

A key challenge faced by transdisciplinary research projects is the ambition of contributing to societal change [70], and the balancing of scientific legitimacy with the process [71]. This need to demonstrate 'success' often means that useful learnings from project failures are not discussed [72]. However, in order to support the development of co-production approaches it is important to outline failings [73]. One key difficulty in the present study was the very flexible and adaptive approach taken to maximise stakeholder input on the research design process [21].

As introduced in Section 2.2, our local partners lacked the resources to effectively engage with the long-term energy planning process. As previously outlined in Watson et al. during an investigation into the Irish community energy network, this was in a large part due to its voluntary nature and insufficient resourcing [74]. Our partners in the local remote working hub (Mol Téic) were concerned about opening the discussion to the wider community before having a clear understanding of how their role in coordinating a local governance structure would evolve. In light of this, it was deemed important to partner with the community development organisation from the area (NEWKD) to develop a strategic plan for the region informed by an assessment of the demographic and socio-economic challenges, and place energy/climate issues within this. It proved to be very fruitful process and has spawned several important initiatives. However, most of these are not directly related to energy. For example, the most significant outcome from the community meetings held was that Dingle has been chosen as Ireland's representative in the EU 'Smart Rural Areas in the 21st Century' network, which is exploring housing options for a dispersed, aging population [75]. The unstructured nature of the participatory process made it very difficult to translate into the energy system model (as has been previously noted [76]), but was necessary to ensure local impact and ultimately provides a better understandings of the problem(s).

There is a risk here that the focus on delivering more practical real-world impact will come at the cost of research outputs, which is particularly challenging for early-stage researchers. Given the limited time intervention available to research projects or doctoral students, uncertainty like this that causes delays in workplans and methodological revisions pose a serious concern to the potential for scientific outputs. This emphasises the importance of having an initial stage to co-design the research process and associated outputs [77], which is not generally facilitated by existing funding structures. In addition, it should be noted the narrow focus within funding on energy technology adoption risks missing a lot of the nuance and complexity [78], which was shown to be of vital importance in this study.

A further consideration that emerged through this process is the need for community development rather than engagement. In moving from consultative engagement practices into more collaborative endeavours, then researchers slip into community development processes. While this may be of great value to the community of interest or collaboration partners, it raises a number of questions on the role of research and evolving responsibility of researchers [20]. A key concern emerging from researchers being core members of the project, in addition to the implications for research integrity/independence [79], is the community group's reliance on expert knowledge. The lead author has regularly offered advice/assistance on energy topics to the local groups, which has been seen as a valuable contribution but begs the question who will fill this role in the future? This makes it crucial to plan for the legacy of the project, and ensure continuation following what is a rather limited intervention by the research project relative to the long-term transformation underway. Moreover, a co-production approach rightly seeks to achieve real-world impact and support local needs ([20,42,43]) but when this involves the coordination or co-funding of community development initiatives it begs the question if this is really the role that research is supposed to play within our society? While it is agreed that this is an important element of a transdisciplinary approach, caution is advised. The expanding role of research(ers) and how this may impact things such as research integrity/independence or the legacy of the project deserves greater consideration. In addition, there is a need to look more broadly at why these gaps in community development coordination and funding exist, and if it is appropriate for research to be filling them.

4.3. Commentary on the prospect of modelling the broader societal transition or stakeholder preferences in quantitative energy system modelling tools

Returning to the central research question (Section 1), a key contribution of this paper is to highlight the value of opening-up discussions on sustainability and resilience in their broader senses rather than that usually facilitated in energy system modelling processes. It highlights some inherent deficiencies in the use of energy system models, particularly at the local level, and raises questions about the current emphasis on model refinements (i.e. seeking to parameterise and incorporate societal elements), which are poorly aligned with user needs [80,81]. As is evidenced here, there are a wide range of considerations and initiatives emerging out of the case study region that cannot be adequately represented in an energy system model (Section 3.2). Moreover, it must be recognised that had the original research plan been followed and discussions limited to what was relevant to the energy system model, much of the broader societal context would have been omitted. In light of this, we feel that a narrow focus on adapting energy system models to socio-technical configurations is misguided. Certainly work can be done to improve modelling approaches and the societal representation within them [12,13]. However, this reductionist approach risks oversimplifying the messiness of the reality within which the energy system must be placed and is thus inappropriate.

What is needed to deliver the rapid societal transformation necessary over the next decade is not more complex models but rather co-production/action research approaches in support of local efforts [15,20], and more collaborative model design processes to ensure new developments remain relevant to policy and other actors [24,80,81]. This research serves to reiterate the need for greater involvement from the social sciences [82]. And more importantly, it calls for modellers (largely energy engineers and energy economists) to be brave in opening up to inter/trans-disciplinary collaborations and face up to the limitations of our methods. This is not to say we should do away with models entirely. As was demonstrated by the scenario results, in particular the gap between the community ambition of energy independence compared to the agreed renewable energy deployment, models remain useful tools for understanding emission trajectories. However, must be presented with humility and respect for the broader societal picture.

4.4. Considerations for future research

The energy scenarios modelled here focused on end year (2030) targets as this was the priority for the local community members, in line with current national policy. As highlighted in sections 3.2, while high-level targets are a good starting point, the pathways to them deserve careful consideration. To better understand these sensitivities further investigation is warranted into the cumulative CO_2 emissions in the various scenarios over the period, which would highlight the importance of earlier versus late action. In addition, while this study focused on energy-related CO_2 emissions, it would be important to include non-energy greenhouse gas emissions such as those in the agricultural sector, particularly in rural areas. Another layer of analysis that was requested by the community partners was to look at the vulnerability to sea level rise, which is already an issue of great concern in one of the communities that is experiencing coastal erosion. This was considered out of scope for the present piece of analysis. However, would be a valuable addition. A previous assessment by Flood et al. highlights that by share of land area at risk to sea level rise, the case study's county is Ireland's forth most vulnerable [83]. Climate change mitigation and adaptation are rarely discussed together, but when working on the local level like in this present study, it would be useful to explore the trade-offs and co-benefits.

With regards the co-production approach, an essential element of opening up energy system models is to more critically evaluate the scenario construction process as opposed to focusing on the results [84]. Facilitating feedback on the results and discussing underlying model assumptions was identified as an important element of a meaningful stakeholder engagement but proved difficult. During a session held with the Corca Dhuibhne Community Energy Group, some initial scenario results were shared, and open questions posed. It was hoped the group would provide feedback on anything they felt was missing from the model, as well as discussing key parameters and the uncertainty surrounding them. However, this detailed look at long-term energy planning was beyound the interest of the group. Given it is made of volunteers with limited time available, there was a preference to focus on individual projects that could be delivered in the next year or two rather than long-term planning exercises. This opening up of energy system models and exploring issues of uncertainty is an important area for further investigation.

5. Conclusion

This study has provided reflections on a co-production approach to energy system modelling. It follows a three-year project, which involved extensive stakeholder engagement to shape the research process and provide insights to inform the energy scenarios developed for the case study region. With regards the methodology, the participatory action research approach that guided the investigation, while posing a serious methodological challenge for the energy system modelling, resulted in a very effective community engagement. The 400 attendees at the fifteen community meetings held is a testament to the value of working with key local stakeholders like community development organisations, who have a strong presence in the area. There is a danger that the increasing calls for more public participation across sustainability science and climate policy result in a 're-inventing of the wheel' when such processes do not capitalize on existing expertise like this. On from this, another central element of this approach was to be respectful of the fact that energy and climate issues are not going to be at the top of everyone's concerns, particularly in struggling rural areas. An important finding in the community engagements was the growing tensions between central national policies and local concerns. It points to the need for new forms of collaboration throughout the policy process, having an honest conversation about the difficult decisions to be made and aligning national objectives with local needs.

The limitations of energy system models highlighted in this study points toward a need to rethink research priorities. Greater attention and resources should be given to co-production/action research approaches that can help deliver the necessary measures while also drawing out vital learnings in the process. As discussed in Section 4.2, there remains some unanswered questions about the evolving role of research and what a co-production approach should entail. While we have raised question on the slipping of research into community development roles, it is evident that there is an important faciliatory role to be played. Transdisciplinary researchers are uniquely placed when they are involved both 'on the ground' in transition processes and building an understanding of people's concerns while also inputting at the upper policy levels. This can help to bridge the gap between bottom-up and top-down stakeholders, supporting the development of well-informed policy to deliver the significant transformation required.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2022.102658.

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Corrigendum

Corrigendum to “Doing things differently: Bridging community concerns and energy system modelling with a transdisciplinary approach in rural Ireland” [Energy Res. Soc. Sci. 89 (2022) 102658]

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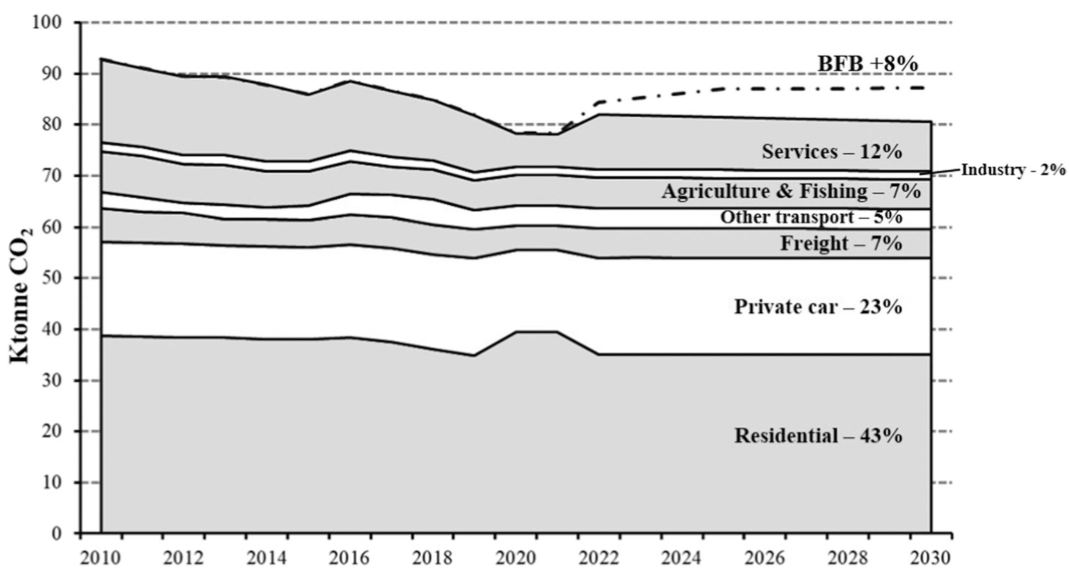
The authors regret that in the original article there were data labels missing from ‘Fig. 2 Dingle Peninsula energy related CO2 emissions by sector in the reference scenario 2010–2030 and projected increase in the build forward better (BFB) scenario’.



The authors would like to apologise for any inconvenience caused.

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