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Developing participatory methods in energy system modelling and planning

Thesis presented by

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for the degree of

Doctor of Philosophy

University College Cork

School of Engineering and Architecture

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Abbreviations

ABM - Agent-Based Model

BEI - Baseline Emission Inventory

BER - Building Energy Rating

CAP – Climate Action Plan

CSO – Central Statistics Office

EMP – Energy Masterplan

ESOM - Energy System Optimization Model

EUI – Energy Usage Indicator

GHG – Greenhouse Gas

GIS – Geographic Information System

GVA - Gross Value Added

LEAP - Low Emissions Analysis Platform

LPG - Liquid Petroleum Gas

MCDA – Multi-Criteria Decision Analysis

NACE - Nomenclature of Economic Activities

NGO - Non-Governmental Organization

NUTS - Nomenclature of Territorial Units for Statistics

SEAI - Sustainable Energy Authority of Ireland

SEAP – Sustainable Energy Action Plan

SEC – Sustainable Energy Community

SDM – System Dynamics Model

SWOT – Strengths, Weaknesses, Opportunities and Threats

TdR – Transdisciplinary Research

UCC - University College Cork

UEC – Unit Energy Consumption

Author's Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.



Connor McGookin

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Executive Summary

This thesis seeks to advance the use of participatory methods in energy system modelling and planning. The necessity for such an approach is threefold: firstly to improve energy system models by placing them in a broader societal context, secondly to facilitate a fair decision-making process in the formation of critical public policy, and finally, to move from climate policy ambition to climate action.

As a transdisciplinary exploration, this thesis is embedded within a regional sustainability project on the Dingle Peninsula in Ireland's south west entitled 'Corca Dhuibhne 2030 / Dingle Peninsula 2030'. Working within the context of a rural peripheral region presented an interesting challenge from an energy system modelling perspective and provided valuable learnings on real-world transition processes. The thesis also pays particular attention to the value of building an understanding of the *societal context* within which the energy system will be placed. The combination of statistical data and lived experience offers a rich insight into the area.

Over the course of the thesis two useful energy system modelling methods were developed. Firstly, developing and applying a new method for determining energy related CO₂ emissions at a sub-national level and secondly, understanding and advancing the meaningful integration of participatory methods in energy system modelling. The results of this thesis demonstrate the challenges associated with aligning national policy decarbonisation objectives with the needs of rural communities. This highlights the clear need to have honest dialogue at local level about possible futures and the co-benefits and trade-offs.

The contributions of this thesis reach across science, policy and society with learnings covering: trade-offs between participatory action research and energy system modelling, value of working across disciplines and with a diverse group of stakeholders, developing the concept of the honest researcher, and supporting an enhanced role for local authorities in delivering climate action. The thesis developed a method to determine a regional emissions profile and approach for scenario analysis bridging participatory methods and energy system modelling. It concludes with a number of interesting areas for further investigation to strengthen the contribution of energy system models to more collaborative forms of deliberation throughout the various policy levels, which may support the radical societal transformation needed.

Thesis outputs

Journal papers

McGookin, C., Ó Gallachóir, B., & Byrne, E. (2021). An innovative approach for estimating energy demand and supply to inform local energy transitions. *Energy*, 229, 120731.

McGookin, C., Ó Gallachóir, B., & Byrne, E. (2021). Participatory methods in energy system modelling and planning – a review. *Renewable & Sustainable Energy Reviews*, 151, 111504.

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McGookin, C., Boyle*, E., Watson, C., Deane, A., & Ó Gallachóir, B. Reflections and learnings from an engaged research project in support of a local sustainability transition. *Research for All*. [Under review]

Boyle, E., McGookin*, C., O'Mahony, C., Byrne, E., Mullally G., & Ó Gallachóir, B. 'Understanding how institutions may support the development of transdisciplinary approaches to sustainability research' *Research for All* [Under review]

Boyle, E., Watson, C., McGookin, C., Deane, A., de Bhailís, D., McElligott, C., O'Hara, S., Tuohy, B., Ó Gallachóir, B. & Mullally, G. (2021). Reflecting on a collaborative approach to a regional sustainability transition: Dingle Peninsula 2030. *Reflective Practice*, 22(3), pp. 416-430.

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‘Imagining Irish Low Carbon and Climate Resilient Futures: a layered Delphi panel approach’.
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Leahy, P., McGookin, C., & Daly, H. (2021). ‘Approximating Professional Practice in a First-Year Engineering Curriculum: The Wind Turbine Maker Project’, *EESD2021: Proceedings of the 10th Engineering Education for Sustainable Development Conference, 'Building Flourishing Communities'*, University College Cork, Ireland, 14-16 June. pp. 297-304. ISSN: 2737-7741 at: <https://cora.ucc.ie/handle/10468/11459>

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Chapter 1 Introduction

1.1 Background

The mounting scientific evidence produced by the Intergovernmental Panel on Climate Change (IPCC) has yet to result in policy and actions that reflect the urgency of this pending crisis. At a global level, the 2015 Paris Agreement signalled a commitment to keep temperatures well below 2°C (United Nations Framework Convention on Climate Change, 2015). However, efforts to outline pathways to the target have been inadequate to date (United Nations Environment Programme, 2021). In response, there has been increasing calls for scientific roles and approaches, to develop ‘science-based’ policy at various different levels, and also actively support the implementation of measures.

A major source of climate warming greenhouse gas (GHG) emissions is our fossil fuel-based energy system. To understand this element of the problem, energy system models are useful tools that provide insights on potential technical configurations that may reduce our reliance on fossil fuels and eliminate the associated CO₂ emissions. However, a key limitation of these tools is the wickedness of the problem they seek to represent. Our destination for the most part is clear, but the path there and consequences of our chosen route are shrouded in complexity and uncertainty. From a technical perspective, there are unanswered questions on the role unproven technologies like hydrogen, carbon capture and negative emission technologies will play (Pye et al., 2021). This has prompted growing debate on the extent to which lifestyle changes are needed to reduce energy demand (Cozzi et al., 2020), as well as a need to look beyond energy and address the impact of our diet (Stehfest et al., 2009). Moreover, there have been serious questions asked of the compatibility of the dominant growth based neoliberal economic model with a low carbon society (Barry, 2012), (Raworth, 2017), (Gough, 2017), and our ability to deliver the necessary climate mitigation measures in a fair and just manner (Robinson, 2018), (Robinson and Shine, 2018).

When it comes to the actual implementation of the measures currently available, there has also been plenty of controversy. The current weaknesses in public engagement practices and tensions surrounding the placement of large-scale energy infrastructure projects threaten to slow the rate of decarbonisation and cast a negative public image over technologies that are vital in our fight against climate change. From an engineering perspective, Ireland has one of the most remarkable electricity networks. A leader in the integration of variable renewable sources, it hosted the highest share of onshore wind energy (36% of electricity demand) in the

world in 2020 despite being an island with limited interconnection (Komusanac et al., 2021). However, this rapid deployment of onshore wind energy over the last decade and upgrades to the electricity transmission system (in the form of new overhead pylon routes) has sparked significant local opposition. The network of opposition groups united under Wind Aware Ireland represents fifty-one local communities from across the country (Wind Aware Ireland, 2021). Another case that has received widespread public attention was the strategy from the transmission system operator Eirgrid ‘*Grid25: A Strategy for the Development of Ireland’s Electricity Grid for a Sustainable and Competitive Future*’, and in particular the North-South Interconnector project (Eirgrid plc, 2008). The North-South Interconnector seeks to improve connectivity across Ireland’s all island electricity grid and is seen as vital to the stability of an electricity network with increasing share of variable renewable sources but has been in a bitter stalemate for over a decade now (McGookin et al., 2021f). There have been a number of planning and high court appeals mounted by the local opposition group, North East Pylon Pressure (NEPP) campaign, arguing for an undergrounding of the cables (North East Pylon Pressure, 2008). The emergence of these coordinated opposition groups highlights weaknesses in planning and decision-making processes.

The opposition to wind energy and overhead pylons is a complex and interconnected issue that is often attributed to concerns over potential impacts on health, landscape, or the local environment (Devine-Wright, 2005). However, as seminal literature on the topic has highlighted, it’s clear that this in in a large part due to the structure of the planning system, which offers very limited public input to design and placement of such technologies (Bell et al., 2005). When input is limited to submissions on planning applications, people inevitably feel excluded from the process and perceive that much of the decisions have already been made by technical experts (Knudsen et al., 2015). This trust in actors and procedural fairness is often further strained by perceptions that the interests of developers and national objectives are being put before the concerns of local people (Mullally and Byrne, 2015). The limits of this technocentric approach have been extensively outlined in the literature and spawned an increasing call for more open and democratic process on key issues like energy and climate policy (Gibbs, 2000).

Deciding on the future of our energy system and indeed society is the democratic right of citizens. Yes, energy engineers can propose models of technological fixes to remove CO₂ emissions from our energy system. However, a much broader societal transformation is required if we are to make the radical changes needed. The traditional technocentric approach

to energy system planning will not be sufficient. New approaches are needed that seek to collaborate with a diverse range of stakeholders in order to develop a shared vision for the future (Waisman et al., 2019). In line with this, given the growing urgency of (un)sustainability issues like climate change, it is clear that research must seek to actively support the implementation of measures (Miller et al., 2014), (Polk, 2014), (Fazey et al., 2018).

1.2 Research aim and questions

This thesis seeks to explore how participatory methods in energy system modelling and planning may open key decisions to a broader range of stakeholders. The pursuit of participatory methods emanates from three motivations. Firstly, it provides a better understanding of the societal context within which the energy system is ultimately placed, going beyond the techno-economic representations offered by conventional energy system modelling tools. Secondly, it facilitates discussion and debate on the range of options available. It should be noted that the goal here is not necessarily to achieve outright consensus on the best path forward, but to facilitate greater dialogue during the decision-making process, and thus, improve procedural fairness. In doing so, producing more socially robust climate mitigation policy measures with a far greater chance of success. Finally, and most importantly, is the move from planning to implementation through support for real-world climate action.

The investigation has been guided by the following research questions:

- 1) What is the present state-of-the-art with regards stakeholder participation in energy system modelling and planning?
- 2) How can we use energy system models to best inform local energy planning?
- 3) In what way is it appropriate to bring the (qualitative) insights from the stakeholder engagement into the (quantitative) energy system modelling tools?

1.3 Thesis outline

This section serves to clarify my contributions within the thesis and credit the collaborations that strengthened it along the way. The chapters in this thesis are based on three journal papers for which I am lead author (2 already published and 1 currently in review). There are a number of other journal papers, a book chapter, a conference paper and several co-authored contributions (as outlined in Thesis outputs) that are referenced throughout the text when appropriate. An overview of the thesis chapters and linkages to the research questions outlined in Section 1.2 is provided in Figure 1-1.

Chapter 2 - Is based on a literature review I conducted. Given that this thesis draws on a broad range of engineering and social science knowledge, it is important to outline some key concepts. In addition, it is useful to explore the contemporary debates that the work seeks to contribute toward and principles that have guided the approach taken.

Chapter 3 – Is a published journal paper for which I was the lead author. I conducted the systematic review of the literature and prepared a draft of the text before going through a review process. Brian Ó Gallachóir and Edmond Byrne provided feedback throughout the analysis and review of the paper drafts. It assesses the progress to date in democratising key decision-making processes within energy system modelling and planning. This provides insights to shape the methodology pursued in Chapter 5.

Chapter 4 - Is a published journal paper for which I was the lead author. I conducted a review of the literature, performed a detailed technical analysis and prepared a draft of the text. Brian Ó Gallachóir and Edmond Byrne provided feedback throughout the development of the methodology, implementation, analysis, and review of the paper drafts. Following an initial review of Irish and international literature examples of how to estimate energy related CO₂ emissions below the national level in the absence of recorded energy data, it was found that literature to date on this topic has been inconsistent and lacked a clearly agreed methodology. In addressing this gap, through the use of an isolated rural case study region I developed a framework for conducting such an analysis.

Chapter 5 – Is a journal paper that I was lead author on that is currently under review. I was responsible for the community engagement process carried out, development of the energy system model using LEAP (Low Emission Analysis Platform) and preparation of the paper. Tomas Mac Uidhir provided feedback and support during the model development phase, as well as reviewing the paper drafts. Brian Ó Gallachóir and Edmond Byrne provided feedback throughout the development of the methodology, implementation, analysis, and review of the paper drafts. Taking the learnings from the previous two chapters, this is the central piece of analysis within the thesis. It explores the implications of taking a co-production approach to energy system modelling, providing important insights into the use of energy system models and reflections on the co-production approach pursued.

Chapter 6 – The thesis concludes with a discussion on the key learnings, contributions of the work across science, society and policy, key recommendations emerging from the investigation and finally some considerations for future research.

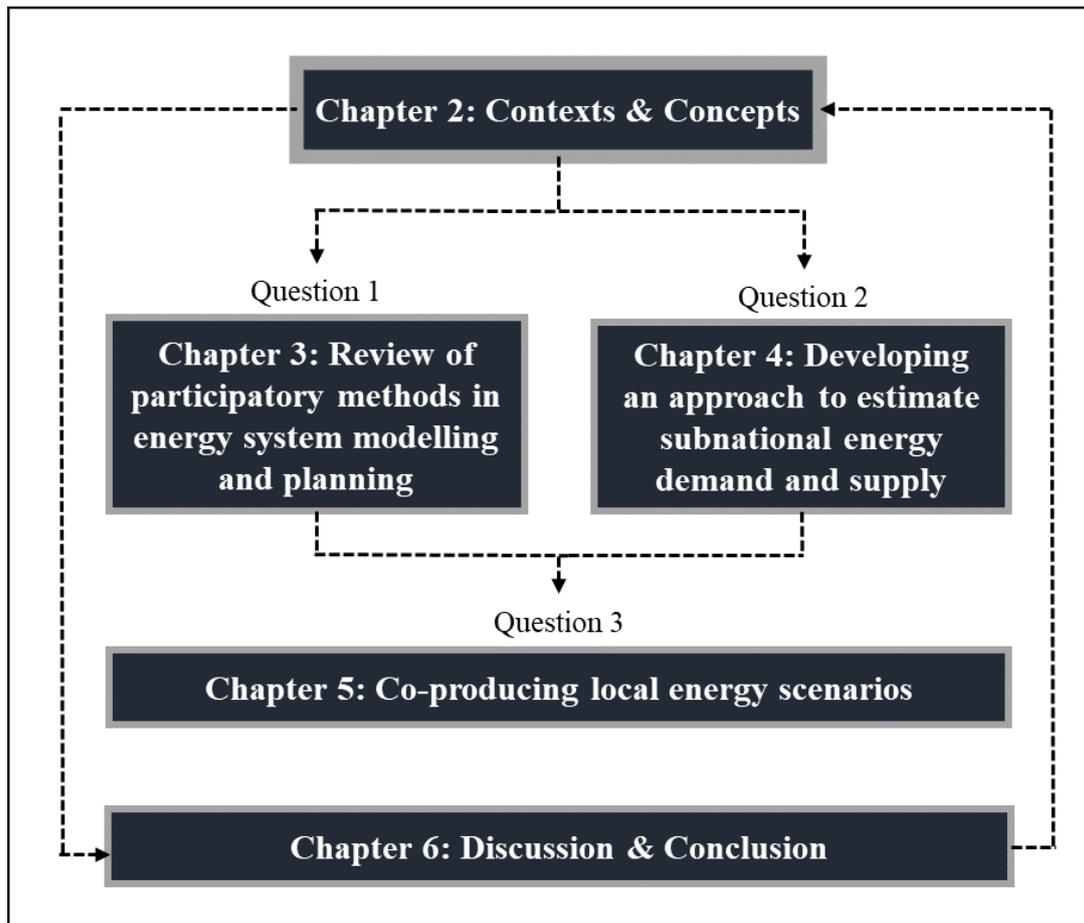


Figure 1-1. Overview of the thesis structure

1.4 The journey

As a transdisciplinary exploration, there were a number of different elements to the training and development over the course of this thesis. At the beginning, a number of modules were undertaken to provide an introduction into sociology, planning and also community-based participatory research, which stems from public health research.

Table 1-1 – Name and module code of modules studied in University College Cork

Community-based participatory research	PG6025
Sociology of the environment	SC3029
Scientific Outreach and Communication	PG6014
Planning Processes, Administration and Participation	PD6114

There was also a lot of practical training on participatory methods and facilitation skills undertaken. It was necessary to learn how to handle what may be sensitive situations and get a grounding in some theories underpinning engagement practices.

Table 1-2. Training undertaken over the course of the PhD

Communication and Public Engagement training	1-day course on how to improve presentations
Creative Facilitation	4-day intensive course covering both facilitation theory and practical exercises
Climate Communication training	1-day course on how to present Climate Change topics from Climate Visuals
Engaged Research training	1-day intensive course on engaged research

I was very fortunate to be part of a team that afforded me opportunities to develop facilitation skills and broaden my knowledge through support of other projects. There were two dedicated workshops run by colleagues exploring the topic of community engagement with Irish climate policy from the perspective of researchers and practitioners. I was an active member of the Imaging2050 project, which was very complementary to the investigation in this thesis. Imaging2050 was an Environmental Protection Agency funded project bringing a wide range of academics together to develop innovative approaches for envisioning pathways to a low carbon and climate resilient future. In addition, along with fellow PhD student Evan Boyle, we hosted a couple of workshops during conferences to share and build on our learnings.

Table 1-3. Workshops and events supported over the course of the PhD

Workshop	Lead by	Location / Date	Description
Innovative Methods of Community Engagement. Towards a Low Carbon Climate Resilient Future	Alex Revez Imagining2050	UCC, Cork Ireland 2019	Bringing researchers from across Ireland together to discuss community participation both within sustainability research but also climate action more generally
How do we Engage Communities in Climate Action? Practical Learnings from the Coal Face	Clare Watson MaREI Engaged Research Support Officer	UCC, Cork Ireland 2019	Bringing practitioners from across Ireland together to discuss community participation with climate action

Stakeholder network mapping with Dingle Peninsula community groups	Evan Boyle, Corca Dhuibhne / Dingle Peninsula 2030	Dingle Ireland 2019	Analysis of the diverse stakeholder network developing around sustainability initiatives
Imaging2050 Deliberative Futures Workshops	Alex Revez Imagining2050	Athlone & Ballincollig Ireland 2019/20	4 x 2-day weekend events in two small Irish towns discussing climate resilient futures through a number of innovative techniques
Facilitating sustainability transitions through innovative governance	Evan Boyle Corca Dhuibhne / Dingle Peninsula 2030	IST2020 Conference, Vienna, Austria 2020 (online)	Co-hosted workshop event at IST2020 conference looking at the issue of governance with representatives from the UN, national policymaking, and community level.
Collaborating for a more sustainable society – Enabling team science and inter/transdisciplinary research for sustainability	Paul Bolger Manager of Environmental Research Institute	Envrion Conference, Cork, Ireland 2021 (online)	Training workshop co-hosted as part of Environ 2021, sharing our experience as early-career transdisciplinary researchers and discussing barriers / supports needed

Chapter 2 Contexts & Concepts

2.1 Irish policy context

2.1.1 Public participation in Irish energy and climate mitigation policy

Over the last decade, discourse in national policy around Ireland's low carbon transition has increasingly focussed on public participation, with the emergence of terms like 'energy citizen' and 'sustainable energy communities'. One of the earliest mentions was in the Irish Government's Energy White Paper from 2007, which noted that the renewable energy transition could play an important part in rural / regional development and endorsed greater community involvement (Department of Communications, Marine and Natural Resources, 2007). This was reinforced in the Strategy for Renewable Energy 2012-2020, which noted that achieving renewable energy targets must be a "*collective endeavour*" and highlighted that one of the significant challenges was; "*winning public acceptance around environmental and other impacts and securing benefits for local communities*" (Department of Communications, Energy and Natural Resources, 2012, p. 7).

The Energy White Paper 2015 dedicated a full section to the development of the so-called 'active energy citizen', Chapter 4; From Passive Consumer to Active Citizen (Department of Communications, Energy and Natural Resources, 2015, p. 42). This placed a significant emphasis both on improved community engagement practices around the siting of energy infrastructure, as well as the role of community owned renewable energy projects.

- "*The transition will see the energy system change from one that is almost exclusively Government and utility led, to one where citizens and communities will increasingly be participants in renewable energy generation, distribution and energy efficiency.*"
- "*Improved community engagement will be essential to renewable energy policy making and implementation*"

In 2016, the Sustainable Energy Authority of Ireland (SEAI) launched the Sustainable Energy Communities (SEC) network, through which mentoring support would be provided to voluntary groups working on energy initiatives (Sustainable Energy Authority of Ireland, 2016). This was a follow up to the Better Energy Communities pilot grant scheme that was launched in 2012, replacing the Better Energy Homes scheme and encouraging communities

to come together to plan improvements to the building stock (Sustainable Energy Authority of Ireland, 2018a).

A standout example of public participation in the policymaking process is the Irish Citizen Assembly. Building on the success of previous forums on abortion and marriage equality, the third citizen assembly on Climate Change was held in late 2017 (Citizens' Assembly, 2018). It brought together a representative sample (across age, gender, social class, and regional spread) of 99 citizens to address the question "*How the State can make Ireland a leader in tackling climate change*". Over two weekends of deliberation they prepared thirteen recommendations, which received overwhelming approval during the closing ballot. Most notably, 89% of the Members agreed that there should be a tax on greenhouse gas (GHG) emissions from agriculture and 80% said they would be willing to pay higher taxes on carbon intensive activities if it was clearly ringfenced for climate measures and there were protections put in place for those experiencing energy poverty.

In June 2018, the Department of Communications, Climate Action and the Environment launched a priority area "*Empowering Communities for Climate Action*" under the Project Ireland 2040 development plan (Department of Communications, Climate Action and the Environment, 2018). It offers four funds for rural development, urban regeneration, climate action and innovation which all require community representation. The following year, in May 2019, the All of Government Climate Action Plan was published, detailing the roadmap to meeting 2030 emission reduction targets through 183 actions outlined (Department of Communications, Climate Action and the Environment, 2019). As with the 2015 White Paper, an entire section is dedicated to "*Citizen Engagement, Community Leadership and Just Transition*". Putting a clear emphasis on public involvement with climate mitigation policy.

The Programme for Government agreed in June 2020 had a subsection dedicated to supports for the community energy sector "*Bringing Communities with Us*" and another outlining "*A New Engagement Model*", which stated that to "*develop a new model of engagement with citizens, sectors, and regions as an early priority for Government*" (Department of the Taoiseach, 2020). Most recently, in March 2021, the Department of the Environment, Climate and Communications launched the Climate Conversation seeking both expert and citizen submissions on the upcoming Climate Action Plan 2021 (Department of the Environment, Climate and Communications, 2021b).

2.1.2 Scoping review of public participation in Irish energy and climate mitigation policy

As set out by (Watson et al., 2019b, p. 20), *“Two key principles underpinning climate action in Ireland today are: engaged citizenship and participatory democracy. Two complicating factors are: the need for substantial change and the imperative of acting now”*.

The growing interest in so-called ‘energy citizenship’ within national policy highlighted in Section 2.1.1, while welcomed, has also drawn some criticism. (Lennon et al., 2020) note that paradoxically the current national discourse around ‘energy citizenship’ that seeks to push responsibility into the hands of citizens may in fact be disempowering as it fails to acknowledge the limited capacity and agency people have for taking part. In an investigation into community perspectives of citizen participation with the energy system, (Lennon et al., 2019) found that two key issues were the fact that energy infrastructure is very disconnected from people’s day-to-day experience of energy and opposition may often be motivated by frustration with the decision-making process. The participants expressed concern that *“they have very little choice as to how the transition to a low carbon energy system is to be configured”*, which directly contradicts the notion of ‘energy citizenship’ (Ibid, p. 24). They thus call for co-production approaches both more broadly in enhanced policy-making processes and locally with community ownership models for energy projects.

Despite the high-level policy support for community ownership models, there has been very limited progress in addressing key barriers to development (Watson, 2020). At present, there are over 500 SECs registered with SEAI (Sustainable Energy Authority of Ireland, 2020c). However, recent research has found a very limited number of the groups to be at a mature development stage. (Byrne and O’Regan, 2020) found that given that grant supports available to the groups have a limited focus on building retrofits, only six SECs were taking a holistic approach to sustainability. During their investigation into the motivations behind community level sustainability projects, they found that the emphasis in national policy on short-term individual financial incentives are misguided. Communities want partnership in decision-making processes that effect their futures and to be regarded as part of the transformation process, not consumers at the end of the line. In another study into the current challenges faced by SECs, it was found that as little as 10 may be truly active (Boyle et al., 2021c), (Watson et al., 2019a). As with the concerns raised on current concepts of ‘energy citizenship’, (Watson et al., 2019a) investigating the barriers to community energy projects through SEAI’s SEC

Network highlight that the ambition within the 2019 Climate Action Plan to increase the SEC network to 1,500 groups by 2030 is ‘out of touch’ with the experience of the groups. They highlight the reliance on voluntary contributions and lack of core funding for coordination and administration as key issues that frustrate these local efforts. Importantly, they conclude that until policy barriers in the form of tariffs, planning, finance, and grid access are addressed, it is unhelpful to continuously talk up community ownership of energy. Given the difficulty in defining the community ownership of energy, (Revez et al., 2020) have suggested that better alternatives lie in emphasising meaningful participation and a fair planning process.

Ireland’s response to climate change to date has been extremely poor, earning it the title of ‘climate laggard’, having been consistently one of the EU’s worst performing countries (Torney, 2020). In light of this, the recent wave of policy and governance innovation is striking (Torney et al., 2020). Most notably, the Citizens’ Assembly has received international recognition as an important deliberative forum for examining pressing social, environmental and political issues (Devaney et al., 2020). It took place over two weekends, with ninety-nine representative citizens informed by expert witnesses, producing thirteen recommendations on “*How the state can make Ireland a leader in tackling Climate Change*” (Citizens’ Assembly, 2018). While feedback from participants was very positive and complimentary of the ‘neutral’ space created for deliberation (Farrell et al., 2019), the follow-up on the recommendations has been limited. A Joint Oireachtas Committee on Climate Action (JOCCA) was set up in July 2018 to consider the Citizens’ Assembly’s on climate change recommendations, and significantly, despite some public debate on carbon tax, published forty recommendations with cross-party support (Torney, 2020). However, there was no clear linkage with those proposed by the citizen’s assembly. (Devaney et al., 2020) in their review of the process highlight that while it offers an important step toward more inclusive and collaborative governance, there is a need for a strengthening of communication on how the recommendations are utilized. Similarly, following a review of the current energy sector governance structure in Ireland, (Torney, 2018, p. 10) points to the need for a stronger framework to enhance “*the two-way flow of information between local communities, national policymakers and other stakeholders*”.

2.2 Public opposition to energy infrastructure

2.2.1 Scoping review of public opposition literature

Many of the barriers to the development of energy infrastructure are non-technical challenges that are dynamic and context dependent. In the case of opposition to wind energy, existing research has shown a complex variety of conditions that shape public perception including physical, contextual, political, socio-economic, social, local and personal aspects (Devine-Wright, 2005). Similarly, bioenergy across Europe has been met with concerns dependent on site specific characteristics like plant size and location, as well as fears of environmental concerns (Fytili and Zabaniotou, 2017). Likewise, literature on the topic of public perceptions to overhead high-voltage transmission lines has explored several differing reasons for local opposition, highlighting that public responses to infrastructure is highly complex issue. There is extensive literature available on the topic of public opposition to energy infrastructure, as highlighted by those included within Table 2-1, which provides an overview of some of the predominant themes.

Table 2-1. Commonly noted causes of public opposition to energy infrastructure

Ref.	Focus	Issue	Description
(Devine-Wright and Batel, 2013), (Lienert et al., 2017), (Tempesta et al., 2014)	Overhead pylons	Landscape impact	The development is out of character with the current landscape and is perceived to negatively change the identity of the place. Also, often an issue when sited near protected areas.
(Carlisle et al., 2016), (Späth, 2018)	Solar PV		
(Warren et al., 2005), (Ladenburg and Dubgaard, 2007), (Strazzera et al., 2012), (Dimitropoulos and Kontoleon, 2009), (Jobert et al., 2007), (Pasqualetti, 2013)	Wind energy		
(Stadelmann-Steffen, 2019), (Bertsch et al., 2017), (Wadley et al., 2019), (Cotton and Devine-Wright, 2013)	Overhead pylons	Health concerns	Perceived risk to electromagnetic frequency

(Pedersen and Waye, 2007), (Shepherd et al., 2011), (Pawlas et al., 2012), (Doolan, 2013), (Onakpoya et al., 2015), (Burton et al., 2011), (Dai et al., 2015)	Wind energy		Noise, infrasound, electromagnetic frequency & mechanical hazards
(Burton et al., 2011), (Dai et al., 2015)	Wind energy	Visual impact	Shadow flicker, which occurs when the turbine blades intermittently block sunshine
(Bond and Hopkins, 2000), (Sims and Dent, 2005)	Overhead pylons	Property value	Proximity to the development may reduce land and property prices
(Carlisle et al., 2015)	Solar PV		
(Graham et al., 2009), (Sims and Dent, 2007)	Wind energy		
(Drewitt and Langston, 2006), (Kuvlesky Jr et al., 2007), (Graham et al., 2009), (Burton et al., 2011), (Dai et al., 2015)	Wind energy	Wildlife / environment impacts	Reduction in birds or other species, soil erosion and deforestation
(Jenssen, 2010), (Fytili and Zabaniotou, 2017), (Bourdin et al., 2020)	Bioenergy	Local pollution (smell, noise, etc.)	Runoff or leakage from the site, usually posing a risk of contaminating water supply
(Fytili and Zabaniotou, 2017), (Bourdin et al., 2020)	Bioenergy	Scale	The size of the development is too large for the area, usually associated with excess traffic in case of bioenergy
(Carlisle et al., 2016)	Solar PV		
(Graham et al., 2009)	Wind energy		

While the issues outlined in Table 2-1 may help to explain public responses to energy technologies, they offer a rather narrow technical focus. Framing public opposition in this manner, often reduces the question down to *what's wrong with the technology?* This omits a lot of the complexity and context surrounding these issues. A more appropriate framing, as will be explored in the rest of this section, would be *why do people feel this way?*

One of the earliest and most notorious framings of public opposition is ‘Not In My Back Yard’ syndrome or NIMBYism, which became prominent in international literature and public discourse during 1980s nuclear debates (Welsh, 1993), (Wexler, 1996). It is often used to describe the phenomenon that despite public opinion surveys generally showing strong support for new energy infrastructure or climate mitigation, projects often experience local opposition (Wolsink, 2000). This positions local community opposition as a threat to the greater societal good and something to be overcome. As noted by (Lake, 1993, p. 91), the ‘irrational obstructionism’ narrative fails to “*recognize it for what it is: an expression of people’s needs and fears*”. It has been extensively criticised in literature over the last two decades as an overly simplistic technocratic approach, in particular highlighted by the seminal works of (Wolsink, 2000), (Wolsink, 2006), (Wolsink, 2007), (Devine-Wright, 2005), (Devine-Wright, 2009), (Burningham, 2000), (Bell et al., 2005), and (Gross, 2007). As outlined by (Aitken, 2010), using the case of wind energy opposition in the UK, it is built on series of flawed assumptions.

- The majority of the public support wind energy development, and thus any opponents are irrationally deviant
- This is in a large part due to misinformation or ignorance
- The purpose of understanding opposition is to overcome it

One of the key issues with this technocratic framing is the narrative of the information deficit model; whereby public opposition is seen to be driven by a lack of clear information on or poor understanding of the proposed developments. There is a tendency to label all opposition as NIMBYism, and subsequently dismiss it as ignorant and selfish (Burningham, 2000), (Wolsink, 2007), (Wolsink, 2012), which fails to “*reflect the complex, multidimensional nature of forces shaping public perception*” (Devine-Wright, 2005, p. 134). (Devine-Wright, 2009) provides an alternative framing in place theory that helps to explain how such developments may be perceived as a threat to people’s attachment to place and established values. An important consequence of the characterisation of local communities as poorly informed is how it may influence the engagement practices undertaken. (Burningham et al., 2015) investigating developer’s perceptions of opponents to wind energy projects found this to be the dominant ‘imagined public’. The consequence of this was that they then follow “*the classic deficit model of public understanding in which members of the public are conceptualized as empty vessels that simply need to be filled with correct information in order to think as the experts do*” (Ibid, p.251). There is an assumed position that those in favour of the developments have the ‘correct’ knowledge, while those who oppose it are simply ignorant or just plain wrong.

A further explanation for the emergence of local opposition, is the ‘democratic deficit’ (Bell et al., 2005). As (Wolsink, 2000) suggests, public opposition is a direct product of the design of the planning process. The standard model involves plans being drawn up by developers, which are only announced to the public during a period of consultation to secure a planning application for specific sites. This effectively limits input to criticism rather than support. Emanating from this, as outlined by (Gross, 2007), a perceived lack of fairness in the decision-making process may spark conflict. As the societal engagement takes place after most of the decisions have already been made, members of the public rightly feel excluded from the process. In line with this, (Wolsink, 2007) calls for an ‘ecological modernization’ of planning regimes and decision-making practices (as defined by (Gibbs, 2000)). Three key characteristics of this would be:

- Open, democratic decision-making, rather than technocratic and corporatist-style decision-making.
- Participation and involvement from a broad stakeholder group rather than ‘experts’ solely carrying out planning and decision-making
- Open-ended approaches that allow multiple views to be expressed, rather than the imposition of single, closed-ended proposals.

On from the issue of procedural fairness, questions also arise around the trust in institutions and actors responsible for the planning and implementation of energy developments. Additionally, beyond public inclusion in the planning process, there has been much discussion on community ownership models and ways of sharing the benefits of projects. A brief overview of these broader considerations is provided in Table 2-2.

Table 2-2. A broader look at public opposition to energy infrastructure

Ref.	Focus	Common themes	Description
(Devine-Wright, 2013), (Ciupuliga and Cuppen, 2013), (Knudsen et al., 2015), (Mueller, 2020)	Grid development	Procedural fairness / justice	Public feel excluded from key decision-making processes, or that they have limited ability to influence the outcome
(Wolsink, 2007), (Eltham et al., 2008), (Hall et al., 2013)	Wind energy		

(Devine-Wright, 2013), (Ceglarz et al., 2017), (Mueller, 2020)	Grid development	Trust in actors and institutions	Public distrust of or disagreement with developers, energy companies, semi- state institutions, government
(Graham et al., 2009), (Hall et al., 2013)	Wind energy		
(Carlisle et al., 2015), (Kalkbrenner and Roosen, 2016)	Solar PV		
(Hall et al., 2013)	Wind energy	Equity / distributional justice	Unfair distribution of costs and benefits
(Simpson and Clifton, 2016)	Solar PV		
(Dale et al., 2013)	Bioenergy		

Crosscutting all of these issues is the question of scale. As (Byrne, 2017) outlines, the transition of the electricity system to renewable energy sources through the uptake of small-scale, distributed microgeneration technologies (such as rooftop solar PV) would switch the balance from a very centralized top-down model to a more decentralized bottom-up one. The perceptions of exclusion, which underpin the issues outlined in Table 2-2, may in part be explained by the fact that proposals to date have been predominately large-scale developments, while those interested in smaller-scale (community level) or microgeneration (household level) face a number of regulatory and policy barriers (Brummer, 2018), (Mirzania et al., 2019), (Inês et al., 2020). As (Späth, 2018) highlighted using the example of solar PV, people demonstrate a preference for smaller rooftop installations as oppose to larger ones covering fields, and thus it is important to find a balance between the two in order to secure public support for renewable energy development. Locally organised smaller-scale renewable energy sources (or community energy) can support fair public participation both in the planning process (Wolsink, 2018), but also importantly, by allowing people to become active members of the energy system (Kalkbrenner and Roosen, 2016).

Addressing the common themes outlined in Table 2-2, two central ways forward are to improve the decision-making procedures both at a local level but also importantly in national policy settings, and also to look at ways of more equitable distribution of energy projects. When these conditions are met, then trust in the actors and institutions is likely to follow. With regards energy research, emerging areas for investigation include but are not limited to: new forms of dialogue during the energy system planning process, understanding public preferences for new

models of community ownership/involvement, exploring the balance between small and large scale projects, analysis of the spatial distribution of technologies, and the quantification of costs/benefits associated with energy infrastructure. A summary of these is provided in Table 2-3.

Table 2-3. The ways forward for energy system planning

Issues	Way forward	Ref.
Procedural fairness / justice	Open and transparent planning and decision-making processes	(Wolsink, 2007), (Ciupuliga and Cuppen, 2013), (Langer et al., 2016), (Firestone et al., 2018)
Trust in actors and institutions		
Equity / distributional justice	Community ownership models / benefit schemes	(Walker et al., 2010), (Bauwens et al., 2016), (Schumacher et al., 2019), (Vuichard et al., 2020)
	Analysis of spatial distribution of technologies and associated costs/benefits	(Balta-Ozkan et al., 2015), (Li et al., 2016), (Sasse and Trutnevyte, 2019)

2.2.2 Public opposition to energy infrastructure in Ireland

The growing interest in public participation outlined in Section 2.1.1, may in a large part be spurred by growing discontent around the placement of energy infrastructure. Ireland’s most successful climate policy to date has been the significant growth of onshore wind energy. In the last decade (2010 to 2020), the installed capacity more than trebled from around 1300 MW to 4300 MW (Sustainable Energy Authority of Ireland, 2020b), which meant it accounted for roughly 36% of total electricity demand in 2020 (Wind Energy Ireland, 2021). This places Ireland as a world leader for onshore wind energy development and the associated grid integration challenges (Renewable Energy Policy Network for the 21st Century, 2020). However, it has also spawned significant local opposition. The lobby group Wind Aware Ireland established in 2014 to coordinate local and national protests against wind energy development represents around fifty opposition groups nationwide (Wind Aware Ireland, 2021). That same year (2014), the National Economic & Social Council in their report ‘Wind Energy in Ireland: Building Community Engagement and Social Support’, called for “A *genuine and open participatory process for wind energy*” as one of three critical components along with having a well-informed national energy strategy and intermediary actor support (National Economic & Social Council, 2014, p.4). As can be seen in Table 2-4, the Irish literature on the topic of public opposition to wind energy echoes much of that outlined in Section 2.2.1.

Table 2-4. A summary of Irish literature on public opposition to wind energy

Ref	Issue / theme	Key findings
(Brennan and van Rensburg, 2020, p. 13)	Procedural fairness	<i>“respondents want greater levels of participation and engagement in wind farm planning and design than is currently permitted under statutory legislation”</i>
(Walsh, 2018, p. 242)	Community energy projects	<i>“Emphasis must be placed on both technical and financial support, as well as engaging communities in agenda setting via community development plans that account for local perceptions of what their ‘community’ means to them”</i>
(Brennan et al., 2017, p. 1977)	Lack of trust in actors	<i>“There was a general consensus amongst community participants that wind farm developers were taking advantage of Ireland for their own gain”</i>
(Brennan and Van Rensburg, 2016, p. 363)	Openness / transparency	<i>“Respondents exhibit a strong preference for a local community representative that would act on behalf of residents affected by a potential wind farm development and provide information and open dialogue between residents and the developer about the wind farm project”</i>
(Van Rensburg et al., 2015, p. 19)	Scale of developments	<i>“the most important project technology variables are project area, rated output capacity, and hub heights”</i>

In line with this growth in onshore wind energy, and in a large part emanating from it, Ireland’s transmission system is badly in need of strengthening. Eirgrid, the Irish transmission system operator, originally set out its plan for grid improvements with its ‘Grid25-A Strategy for the Development of Ireland’s Electricity Grid for a Sustainable and Competitive Future’ published in 2008 (Eirgrid plc, 2008). It had three central 400-kV overhead lines and associated pylons proposed to strengthen connections across the country: from South to East (“Grid Link”), West to East (“Grid West”) and cross-border between the Republic of Ireland and Northern Ireland (“North-South Interconnector”). It’s important to note that one underlying issue driving these proposals is the need to connect the large share of the Irish population/economy living on the east coast and wind energy resources along the west coast. The Greater Dublin Area surrounding the capital city houses around 40% of the Irish population and over 50% of Gross

Domestic Profit (GDP) (Dublin Chamber, 2021). In addition, as noted in Section 2.2.1, underpinning these issues is the question of scale and who benefits from the developments. Eirgrid, very recently launched its Shaping Our Electricity Future Roadmap following extensive public consultation. It included an expectation for 500MW of microgeneration in Ireland by 2030 (Eirgrid plc, 2021), which would represent a significant switch away from what to date has been primarily large-scale developments.

Important considerations emerge when exploring the broader context and discourse surrounding one particularly controversial proposal to improve interconnection to the UK and export wind energy generated in the Midlands (one of the country's less affluent regions). As noted by (Mullally and Byrne, 2015), this feed into a narrative of historical injustice, which sparked huge unrest at the notion that Irish communities would bear the cost while UK private interests the gains. This was captured in one of the protester's slogans at the time "*Welcome to the midlands, England's offshore wind farm*" (Ibid, p. 13). Another investigation into the narratives of the supporting and opposing groups highlights how the conflicting conceptualizations of the rural 'resource' and framings (national versus local) means that the two sides "*talk 'past' each other rather than 'to' each other*" (Lennon and Scott, 2017, p. 104). To the proponents of the development the value in terms of economic gains is clear, but to the local opposition, there is no clear benefits that can outweigh the 'industrialization' of the rural landscape. On from this, questions have been raised about what is conceived to be the 'public interest' and who gets to define it (Lennon and Scott, 2015), which is a particularly challenging issue when projects such as this that are vital in the national interest clash with local concerns.

A legacy of this controversy was to conflate in the public eye grid developments with wind energy and highlight that the costs and benefits of such energy infrastructure would not be shared equally. The narrative that emerged around external private gains at the expense of the rural communities has been reflected in public opposition campaigns across the country. Increasingly, the national ambition for the reduction of CO₂ emissions is positioned as having little regard for the concerns of rural communities and providing limited local benefits. This highlights the value of paying greater attention to the context and framings surrounding energy infrastructure. As set out by (Lennon and Scott, 2017, p. 105), there is a need "*to work through conflict and preserve difference rather than being paralysed by polarised positions*". A more meaningful dialogue and deliberation process may unpack meta-issues such as the growing inequality between rural and urban areas in order to develop well-informed climate and energy policy. As (Mullally and Byrne, 2015, p. 18) conclude, addressing the question of public

opposition in Ireland is “not just about the need for better public engagement but also the need to create institutional opportunities to allow for this engagement to take place”. Improved communications channels are needed to facilitate a better understanding between top-down and bottom-up stakeholders so that vital national objectives such as climate policy are not positioned as coming at the cost of local concerns.

2.3 Engineering in the 21st Century

2.3.1 Wicked problems

The term ‘wicked problem’ was coined by Horst Rittel and Melvin Webber in 1973 (Rittel and Webber, 1973). They use it to make distinction between complex policy planning questions that do not have conclusive answers and the “tame” or “benign” problems scientists and engineers generally deal with:

“Planning problems are inherently wicked. As distinguished from problems in the natural sciences, which are definable and separable and may have solutions that are findable, the problems of governmental planning--and especially those of social or policy planning--are ill-defined; and they rely upon elusive political judgment for resolution. (Not "solution." Social problems are never solved. At best they are only re-solved--over and over again.) (Ibid, p. 160)

In formulating their definition, Rittel and Webber provide ten characteristics that make problems wicked. These have been outlined in Table 2-5..

Table 2-5. Ten characteristics of wicked problems (Rittel and Webber, 1973)

- | |
|--|
| <ol style="list-style-type: none">1) There is no definitive formulation of a wicked problem.2) Wicked problems have no stopping rule.3) Solutions to wicked problems are not true-or-false, but good-or-bad.4) There is no immediate and no ultimate test of a solution to a wicked problem.5) Every solution to a wicked problem is a ‘one-shot operation’; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.6) Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.7) Every wicked problem is essentially unique.8) Every wicked problem can be considered to be a symptom of another problem. |
|--|

- 9) The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
- 10) The planner has no right to be wrong.

More recently, (Farrell and Hooker, 2013, p. 686) have simplified this into the following three characteristics.

- Finitude; it is not possible to process/analyse the problem entirely, *“we are ignorant, not just of the facts and true theories, but of methods for validly establishing these, the concepts required to specify them and the criteria for correctly deciding such things”*
- Complexity: the outcome of interventions is unpredictable, irreversible and context dependent, they cannot be simply understood through deterministic representations. This is due to the fact *“(A) It will often be impossible to disentangle the consequences of specific actions from those of other co-occurring interactions. (B) The outcomes of processes are difficult to predict, amplifying our ignorance and exacerbating the limits imposed by finite resources.”*
- Normativity: different actors/agents can have different legitimate perspectives (or framings) of reality and hence value different interventions. *“Human values and norms can become inextricably intertwined with problem formulation and problem resolution”*

One of the ways in which to understand wicked problems is through the lens of ‘worldviews’, as described by (Koltko-Rivera, 2004, p. 3) worldviews are *“sets of beliefs and assumptions that describe reality”*. The term originates from the German word ‘Weltanschauung’, which means a particular view or perspective of the world held by an individual or group. (Hedlund-de Witt and Hedlund-de Witt, 2013) define worldviews as *“inescapable, overarching systems of meaning and meaning-making that to a substantial extent inform how humans interpret, enact, and co-create reality”*. A key design challenge posed by wicked problems is that what people consider valid for both the initial problem framing and desirable solutions will be determined by their worldview. Tackling such problems thus requires collaboration with stakeholders from a diversity of backgrounds, disciplines, and experience. This does not necessarily mean agreement will be reached on the problem definition or interventions; but rather that stakeholders build an understanding of each other’s positions or ‘worldviews’ well

enough to have ‘authentic dialogue’ about the different interpretations, and on from this, collectively agree a way forward.

In his book, *‘Citizens, Experts, and the Environment’*, (Fischer, 2000) calls for meaningful non-expert involvement in policymaking and demonstrates the value of deliberation, combining local contextual knowledge and professional expertise, to solve complex social and environmental problems. (Innes and Booher, 2004, p. 419), similarly outline, in their seminal review of public participation within US policy planning, that *“collaborative participation can solve complex, contentious problems”*. This they note requires authentic dialogue, which involves forums whereby everyone is *“equally empowered and informed and where they listen and are heard respectfully”* (Ibid, p. 428). As they later spell out in their book *‘Planning with Complexity’*, responding to the current era of abundant wicked problems will require the integration of collaborative practices in planning but also importantly public policy (Innes and Booher, 2010).

(Levin et al., 2012) expanding on Rittel and Weber’s original concept, characterise contemporary (un)sustainability challenges like climate change as ‘super wicked’ problems. They propose four additional concerns: *“time is running out; those who cause the problem also seek to provide a solution; the central authority needed to address it is weak or non-existent; and, partly as a result, policy responses discount the future irrationally”* (Ibid, p. 123). Reflecting on how engineering can respond to super wicked problems, (Yearworth, 2016, p. 44) concludes that *“Dealing with worldviews, subjectivity and the fact that we are contributing to the problem in which we are trying to intervene suggests that we need to extend existing methods to deal with more inclusive and widespread participation”*.

2.3.2 The New Engineer

The concept of a new more socially responsible engineer who serves the community as oppose to an employer or client was originally proposed by Sharon Beder in her book *‘The New Engineer’* (Beder, 1998). With an increasing role for engineers in public policy and planning, she outlines the need for greater reflection on the role of engineering in society, as well as engineering practice and ethics in dealing with risk and uncertainty. In her concluding remarks on the role of technical experts in policy decision-making and the need for the new engineer to have a more public role, she notes that:

“Such interaction with the community is necessary to improve the general understanding of the role of engineering and ensure that the engineering viewpoint is considered by the nation’s

decision-makers. It is also important that such comment not be disguised or presented as neutral technical advice, but as the value-based judgment it necessarily is.” (Ibid, p. 248)

More recently, (Conlon, 2008) highlights that engineers need to understand the wider social context in which they work, and reflect on how their involvement with public policy may “*enable or constrain the move towards a sustainable and just world*” (Ibid, p. 156). Similarly, (Mitcham, 2019) seeks to prompt critical reflection on the role of engineering by examining its contribution to society over the last few decades.

As highlighted by the above literature in Section 2.2, the planning of energy infrastructure is a very delicate matter requiring a careful engagement process to understand the social and political context within which the system will be placed. These subjective design requirements make the design of such projects a highly complex wicked problem (Section 2.3.1), which cannot be simply understood through the completion of a least-cost design process. This is precisely where conventional engineering approaches fall short. McGookin et al., examining the Irish North-South Interconnector Project (discussed in Section 1.2.2), demonstrate how the reductionist hubris that dominates engineering education and practice risks adding to public discontent, as local communities often poorly perceive it as arrogant and dismissive (McGookin et al., 2021f). Likewise, (Jonassen, 2000) argues that the lack of recognition for the value of alternative views is likely a result of the predominant culture in science and engineering based on objectivism, positivism, and reductionism. As summarized by (Byrne and Mullally, 2014, p. 241):

“Traditional reductionist models of engineering education seek to extinguish context and uncertainty and reduce complexity across socio-economic and ecological domains. They therefore constitute a wholly inadequate response to the need for fit-for-purpose, twenty-first century graduates required to address broader sustainability issues.”

Modern (fit-for-purpose) engineering must take a more holistic approach. Engineers are necessarily technical experts and should remain so, but it is important to recognise our own inherent biases and respect the alternative perceptions our solutions will encounter when placed into an active society (McGookin et al., 2021f).

2.4 Transdisciplinary research

This thesis is well placed within University College Cork (UCC), an institute that places strong emphasis on approaches to reach across disciplines and work with stakeholders from outside

the university. In the university’s current academic strategy, three out of six pillars are: ‘civic and community engagement’, ‘inter/transdisciplinarity’ and ‘sustainability’ (Office of Deputy President & Registrar, 2018). This is driven by a new research agenda nationally (Campus Engage Engaged Research Working Group, 2017), and at a European level due to the 2017 report “*Investing in the European future we want*” (Lamy, 2017), as well as the Joint Programme Initiative on Climate’s ‘Strategic Research & Innovation Agenda 2016 – 2025’, which lists ‘*Enhanced societal relevance*’ as its first priority (JPI Climate Governing Board, 2016). Internationally, a recent report from the OECD has drawn out the importance of transdisciplinary approaches in addressing societal challenges (OECD, 2020).

The origins of this approach to science are often attributed to (Funtowicz and Ravetz, 1995), who highlighted that given the high stakes and uncertainty presented by contemporary ecological challenges, a ‘post-normal science’ approach that seeks to incorporate experiential (e.g. community, indigenous, local) knowledge is needed. This notion has since been developed further, with a number of additional considerations, as summarized within Table 2-6.. More recently, (Pohl and Hadorn, 2007, p. 11) outline transdisciplinary research as an approach that can:

- a) *grasp the complexity of problems,*
- b) *take into account the diversity of lifeworld and scientific perceptions of problems,*
- c) *link abstract and case-specific knowledge*
- d) *develop knowledge and practices that promote what is perceived to be the common good*

Table 2-6. Overview of commonly stated reasons that a transdisciplinary approach is needed

Ref.	Description
(Funtowicz and Ravetz, 1995)	High stakes and uncertainty call for ‘post-normal science’ that includes experiential knowledge
(Stauffacher et al., 2006)	Real-world knowledge is needed to understand the diversity of problem framings
(Scholz et al., 2006)	A process of mutual learning between science and society to produce new knowledge
(Raymond et al., 2010)	A means of integrating different types of knowledge for local environmental management

(Wiek et al., 2012)	Research needs to generate usable knowledge that matters to people's decisions
(Miller et al., 2014), (Polk, 2014), (Fazey et al., 2018)	Given the urgency of sustainability issues, research must contribute to real-world solutions

With regard energy system modelling and planning, the interest in new forms of participation in the decision-making process, stemming from public opposition to infrastructure (Section 2.2) and a rethinking of engineering's role in public policy planning (Section 2.3), is a relatively recent trend (McGookin et al., 2021c). However, the engagement of non-academic stakeholders in research through approaches like community-based participatory research or other action-orientated approaches is long established in areas like public health, education, and other social sciences (Freire, 1982), (Wallerstein and Duran, 2008), (Scholz et al., 2006), (Kindon et al., 2007). The growing interest of transdisciplinary practice in sustainability science has led to several different interpretations (Scholz et al., 2006), (Mullally et al., 2017). In light of this, it is important to outline the understanding that has guided the approach adopted in this thesis. One prominent definition would be that transdisciplinarity may be considered as involving open interdisciplinary collaboration (undertaken with the necessary prerequisite of disciplinary humility (Byrne et al., 2017)) and seeking new knowledge through participatory methods with stakeholders from outside academia (Scholz et al., 2006).

Transdisciplinary research encompasses a broad field of study and understanding. Thus, it is worth noting some guiding principles that have underpinned the approach adopted in this thesis. The seminal work of (Lang et al., 2012) provided one of the first outlines of transdisciplinary research principles from their review of early examples, it included:

- Establishment of a transdisciplinary committee with a diverse group of academic and non-academic representativeness
- Jointly define the problem, research question(s) and process
- Generate targeted products for both parties
- Evaluate scientific and societal impact

More recently, (Fazey et al., 2018) provide ten essentials for action-orientated climate and energy research, which are outlined below in Table 2-7.

Table 2-7. Ten essentials for action-oriented and second order energy transitions, transformations and climate change research (Fazey et al., 2018).

- 1) Focus on transformations towards low-carbon, resilient living
- 2) Focus on solution processes
- 3) Focus on ‘how to’ practical knowledge
- 4) Approach research as occurring from within
- 5) Work with normative aspects
- 6) Seek to transcend current thinking and approaches
- 7) Take a multi-faceted approach to understand and shape change
- 8) Acknowledge the value of alternative roles of researchers
- 9) Encourage second-order experimentation and change
- 10) Be reflexive

2.5 Scoping review of energy system modelling challenges and debates

There are a very wide range of energy system modelling tools available for different applications across geographic and technical scales, as demonstrated by the many reviews conducted on the topic: (Connolly et al., 2010), (Foley et al., 2010), (Banos et al., 2011), (Suganthi and Samuel, 2012), (Sinha and Chandel, 2014), (Allegrini et al., 2015), and (Ringkjøb et al., 2018). With regards the key focus of this thesis, the integration of participatory methods, a range of tools and approaches are explored in detail within Section 3.5. The purpose of this section is to briefly introduce some of the contemporary debates within energy system modelling to which this thesis will seek to contribute. A summary of these is provided in Table 2-8.

Table 2-8. Overview of key energy system modelling issues

Ref	Issue	Description
(Pina et al., 2011), (Pfenninger et al., 2014), (Collins et al., 2017), (Lopion et al., 2018), (Weinand et al., 2019a),	Temporal and spatial resolution	National models rely on poorly disaggregated spatial data for key variables like renewable energy potentials and system costs. Similarly, time horizons are very long spanning decades and thus often rely on

(Prina et al., 2020), (Aryanpur et al., 2021)		simplified representations of power system variations across years, seasons, days, etc.
(Prasad et al., 2014a), (Sadri et al., 2014), (Coelho et al., 2018), (McGookin et al., 2021b)	Data availability	Datasets are often inaccurate, incomplete or unavailable
(Pfenninger, 2017), (DeCarolis et al., 2017), (Weinand et al., 2020c), (Pfenninger et al., 2017), (Pfenninger et al., 2018)	Transparency and open source	The model building process requires significant modeller judgment with limited standard guidance, and these underlying assumptions are often hidden
(Pfenninger et al., 2014), (Yue et al., 2018), (Wiese et al., 2018), (Pye et al., 2018)	Dealing with complexity and uncertainty	There is huge uncertainty around model parameters such as future technology cost or deployment rates
(Creutzig et al., 2018), (Pye et al., 2021)	Focus on supply-side measures	Models predominately project historical trends based on GDP growth and thus potential demand-side measures, such as a reduction in energy demand are often absent from analysis. This contributes to a reliance on technologies like carbon dioxide removal.
(Li et al., 2015), (McDowall and Geels, 2017), (Geels et al., 2016), (Nikas et al., 2020)	Techno-economic modelling limitations	Models need to look beyond techno-economic representations of the energy system and incorporate real-world behaviour insights. However, complex/dynamic social and political systems are not easily quantifiable.
(McDowall and Eames, 2007), (Kowalski et al., 2009), (Trutnevyte et al., 2011), (Waisman et al., 2019), (Hirt et al., 2020),	Participatory / transdisciplinary approaches	Stakeholder and public perspectives and preferences should be integrated into the energy system modelling process

(Xexakis et al., 2020), (McGookin et al., 2021c), (Sillak et al., 2021)		
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Temporal and spatial resolution

High temporal and spatial resolutions are required in order to adequately consider how the energy system will develop, which is particularly important in the context of the trend towards decentralised energy systems and their interactions with the centralised system (Weinand et al., 2019a). In parallel to this, with growing levels of electrification in heating and transport, detailed load profiles are important to understand the implications for electricity power system planning and operation (Pina et al., 2011), (Collins et al., 2017). (Aryanpur et al., 2021) in a recent review of energy system optimization models demonstrated that estimates for system costs and renewable energy deployment will differ based on the level of spatial resolution. GIS offers one way to address this issue by mapping energy demand and renewable energy potentials (Resch et al., 2014), along with the coupling of power / energy system models (Collins et al., 2018), (Seck et al., 2020), and development of more detailed regional models (Li et al., 2016).

Transparency

An inherent weakness of conventional techno-economic energy system models is that the building process requires significant modeller judgment with limited standard guidance (DeCarolis et al., 2017). Furthermore, the underlying assumptions that determine the output of the model are often hidden (Pfenninger et al., 2018). This lack of transparency undermines the validity of conclusions drawn from the model, which has led to increasing calls for the publishing of methods, data and open source models (Pfenninger, 2017), (DeCarolis et al., 2017), (Pfenninger et al., 2017), (Pfenninger et al., 2018).

Dealing with complexity and uncertainty

Energy system models firstly seek to represent a highly complex system, and then from this attempt to make projections into the future. It is no surprise then that there are several key areas of uncertainty around both model parameters (such as cost of technologies, deployment rate, availability, etc.) and model structure. As (Yue et al., 2018) note, uncertainty is an issue that is widely acknowledged in the literature but rarely assessed. While (Nemet et al., 2017) highlight that experts tend to be overly optimistic regarding the field or technology they are involved in, which leads to an overconfidence bias in future cost reductions and rate of deployment. There

are analytical approaches for addressing uncertainty in key model parameters such as Monte-Carlo or Global Sensitivity Analysis (Rubin et al., 2007), (Yeh and Rubin, 2012), (Pye et al., 2015), (Yue et al., 2018). In addition, the discussion of uncertainty with stakeholders such as policymakers who make use of modelling results is important (Pye et al., 2015), (Pye et al., 2018). As the infamous George E. P. Box quote says, “*All models are wrong but some are useful*” (Box, 1976). Ensuring the appropriate use of energy system modelling insights requires discussion on the underlying assumptions and uncertainty issues.

Whose views do the models represent?

Tied to the issue of uncertainty and transparency, models are generally presented as rational decontextualized technical simulations or least-cost optimizations. In reality however, these are reflections of contemporary debates and the views of the people who build them. (Trutnevyte et al., 2016, p. 336) by retrospectively reviewing UK energy policy from 1978 – 2002 and previous expectations for how it would play out, found that “*scenarios tend to reflect contemporary discussions, concerns and expectations. Meanwhile, scenarios tend to ignore other, equally important aspects that either cannot be so easily modelled as parameters, such as governance arrangements or structural changes in industry, or for which there is a consensus that they are not likely*”. (Xexakis et al., 2020) compared model-based electricity scenario scenarios for Switzerland in 2035 from previous studies against chosen portfolios from energy experts, informed citizens (given factsheets about the technology options) and citizens (not given the factsheets). They found that the model-based scenarios not only didn’t represent the preferences of the two citizen groups but also the experts. Thus, emphasising the importance of engagement with a diverse group of stakeholders during the energy system model building process to ensure that the results are ‘socially robust’.

Techno-economic models don’t represent the real-world

Least-cost optimizations are a bad approximation for how real-world transitions will play out. They assume that people act in a rational manner with perfect foresight, and do not account for the broader social and political context within which the transformation is taking place.

On the one hand, incorporating behavioural insights on technology use and learning curves on technology diffusion into energy system models offers a means to better represent real-world dynamics (Köhler et al., 2009), (Daly et al., 2014), (Rubin et al., 2015), (Brand et al., 2019), (Dubois et al., 2019). For example, modelling the uptake of new technologies as non-linear s-

curves, which mimics diffusion as initially slow before a period of rapid development and then slowing into a steady state rather than a straight linear projection (Köhler et al., 2018).

On the other hand, these highly complex social and political dynamics cannot be adequately modelled with quantitative tools (Li et al., 2015), (McDowall and Geels, 2017), (Geels et al., 2016), (Nikas et al., 2020), (Süsser et al., 2022). In addition, it has been noted that energy systems models rarely explore the negative consequences in the form of social and political disruption (Hanna and Gross, 2021). This has led to calls for bridging between participatory action research and conventional modelling processes rather than a merging of analytical approaches (De Cian et al., 2020), (Geels et al., 2020).

2.6 Corca Dhuibhne / Dingle Peninsula 2030

2.6.1 Project overview

For the past three years, MaREI (the Science Foundation Ireland Centre for energy, climate and the marine) have worked in partnership with Ireland's electricity distribution system operator (ESB networks) and local non-profit organisations from the Dingle Peninsula supporting enterprise (Mol Teic / Dingle Creativity & Innovation Hub) and community development (North East West Kerry Development, NEWKD). In 2019, the title Dingle Peninsula 2030 was agreed along with the unifying vision of supporting projects seeking to improve the long-term sustainability and resilience of the area (Watson et al., 2020). The Irish title *Corca Dhuibhne 2030* is preferred by locals as the area is a protected region of Irish heritage known as a Gaeltacht where Irish (or Gaeilge) remains the first language and is thus used throughout the remainder of this thesis.

The core research team consists of two PhD students from energy engineering (the author) and from sociology, as well as an Engaged Research Support Officer, which was a new role created for the project (MaREI Centre, 2022). The area was identified as providing an opportunity to explore an 'engaged research' approach due a couple of exciting developments taking place. The national distribution system operator (ESB Networks) is running a pilot project (The Dingle Project) to explore the electrification of heating and transport, with local ambassadors trialing technologies such as air-sourced heat pumps, electric cars, batteries and solar PV (ESB Networks, 2018). In line with this, a community lead group based out of the Dingle Creativity & Innovation Hub (Mol Téic), located within Dingle town, seeks to explore the broader societal changes required through a range of initiatives across smart agriculture, sustainable transport,

rural regeneration, eco-tourism and bioenergy (Mol Téic, 2020). Their primary goal is to explore how the ongoing digital transformation and sustainability transition may offer the local community new and interesting employment opportunities.

Our research team has employed a variety of different engagement activities, which is grounded in an engaged research or action-orientated approach, as outlined below by the Irish University Association, Campus Engage.

“Engaged research describes a wide range of rigorous research approaches and methodologies that share a common interest in collaborative engagement with the community and aim to improve, understand or investigate an issue of public interest or concern, including societal challenges.”

(Campus Engage Engaged Research Working Group, 2017, p. 28)

A central component of the project was to establish a collaborative governance committee to coordinate activities in the area (Mol Téic, 2021). This is comprised of seven members from: a board member and the Manager of Dingle Hub, the Local Area Manager within NEWKD (a community development organisation), ESB Network’s Dingle Community Engagement Manager and MaREI’s research team. The committee meets regularly on a monthly or sometimes bimonthly basis. Our reflections on the experience of forming the partnership and collaborating in this manner have been documented in (Watson et al., 2021) and (Boyle et al., 2021b). In line with the key principles outlined in Section 2.4 and developed in the context of this thesis in Section 3.3.1, the purpose of this committee was to facilitate input on the research design (Sections 4.5.2 & 5.3.1), gather reflective learnings and ensure the research actively contributed to local efforts (Appendix 3.A).

2.6.2 My involvement

Figure 2-1 gives an overview of the key engagements that I was involved in coordinating. Following a similar framework to that used by (Trutnevyte and Stauffacher, 2012), it is coded as follows; red indicates a collaboration, green represents consultations (or workshops) and blue are information events. A brief description of each event is provided in Table 2-9.

Table 2-9. Summary of my engagement activities over the course of the Corca Dhuibhne 2030 project

Activity	Event	Description
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Stimulating thinking on the Dingle Peninsula	Tech week, LED Bulb Swap & EMP launch	Public information events co-organised with local partners
Disseminating learnings	Europe Day event	Invited to speak at a special sitting of the Joint Oireachtas Committee on Climate Action
	Discussion with Cobh Zero Carbon, Stoneybatter SEC and Youghal SEC.	Sharing practical learnings and advice, in particular on the process of doing an Energy Masterplan
	Local Climate Dialogues	Symposium on community engagement with climate action co-organised with the Imaging2050 project
	Royal Irish Academy - Better together: knowledge co-production for a sustainable society	Represented Corca Dhuibhne 2030 at a workshop discussing examples of co-production approaches from across Ireland (Bolger et al., 2021)
	SECAD training	Asked to provide content for and present at sustainable community training programme
	Project advisory group for Ministerial Guidelines on Local Authority Climate Action Planning	Invited to advise on the range of methods available for determining a baseline emissions inventory at the local authority level
Facilitating dialogue on the Dingle Peninsula	Student workshop	Workshop organised with students from Dingle peninsula studying in University College Cork
	Stakeholder mapping workshop	Assisted fellow PhD student Evan Boyle deliver a stakeholder mapping exercise, and brief discussion on energy ambitions / challenges (Boyle et al., 2021a)

	Climate Hacks	Event developed and co-organised with Dingle Creativity and Innovation Hub run in the secondary schools during Science Week 2019/2020 (McGookin C., 2020)
	Community meetings	Two rounds of community meetings in the seven parishes that make up the Dingle Peninsula co-organised with local community development organisation (McGookin et al., 2021e)
	Re-imagine workshop	Online workshop co-organised with Dingle Creativity and Innovation Hub to discuss opportunities for the area post-COVID
Collaborative committees	Energy Masterplan	Advised on steering committee setup to oversee the creation of a baseline CO ₂ emission inventory for the area (McGookin et al., 2020a)
	Corca Dhuibhne / Dingle Peninsula 2030	Collaborative governance committee setup, outlined in Section 2.6.1

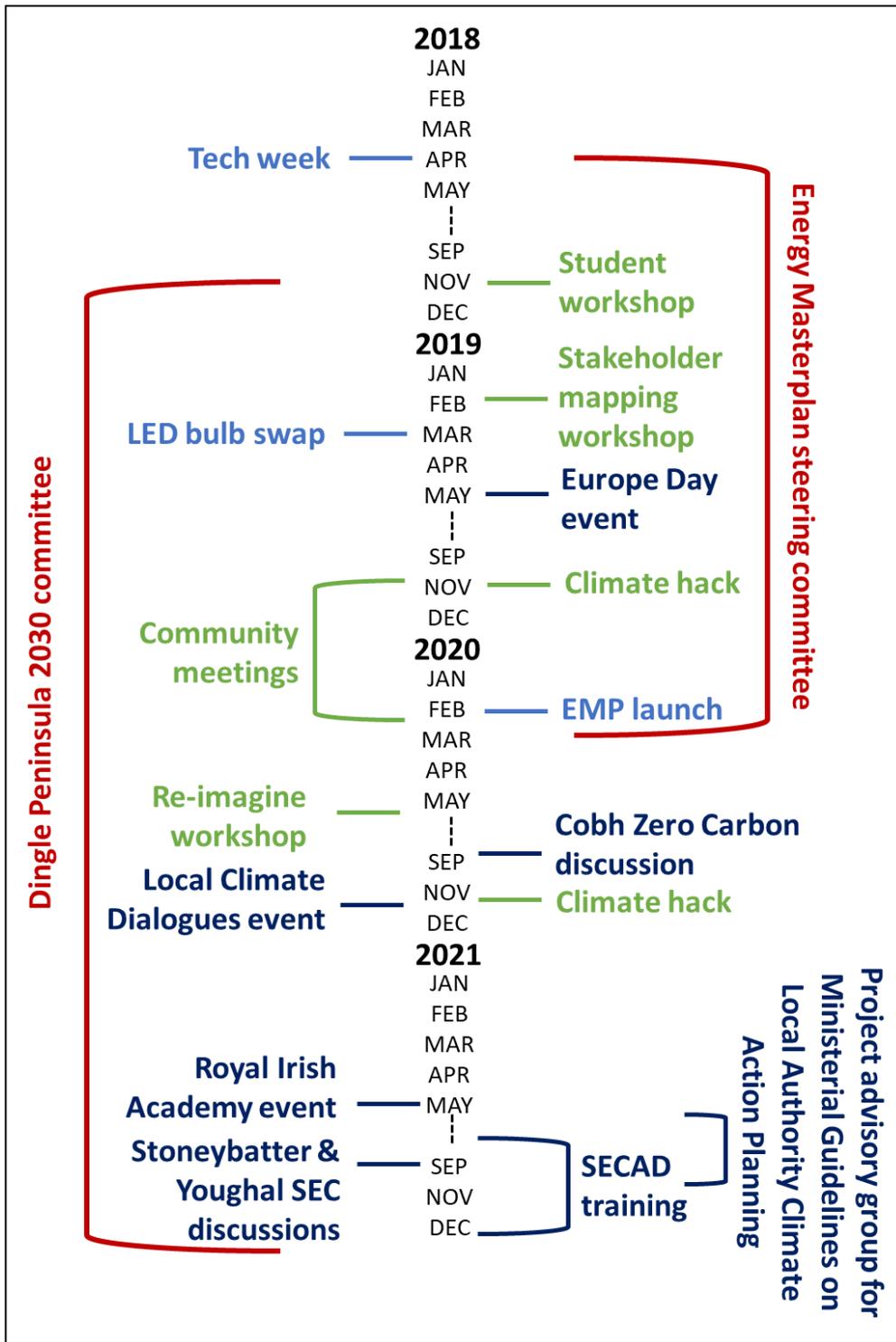


Figure 2-1 – Timeline of my engagement activities over the course of the Corca Dhuibhne 2030 project

Chapter 3 Participatory methods in energy system modelling and planning – a review

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Keywords: Participatory; Transdisciplinary; Energy system modelling; Energy planning; Energy scenarios

3.1 Abstract

This paper presents a systematic review of participatory methods used in energy system modelling and planning. It draws on a compiled database of fifty-nine studies at a local, regional, and national level detailing analysis on full energy systems down to sectors, modes, and single technologies. The initial aim of the paper is to consolidate and present this growing body of literature, providing a clear understanding of which stakeholder groups have been engaged and what methods have been used to link stakeholder engagement with quantitative analysis. On from this, the progress to date in democratising key decision-making processes is discussed, reflecting on the benefits and challenges of a participatory approach, as well as highlighting gaps within the current body of literature. During the review, two differing spatial levels at subnational (cities, municipalities, or regions) and national scale emerged as separate groups for analysis. A clear distinction between the two groups was the motivation for involving stakeholders. At a subnational level, researchers hoping to build local capacity to bring about real-world change engaged with community representatives, whereas national level studies concerned with generating more impactful energy policy measures involved industry, policymaking, and academic experts. One key finding from the review was that only ten out of the fifty-nine studies reviewed noted some form of collaboration with non-academic stakeholders, and moreover 36% of studies involved just a single interaction with participants. This indicates a lack of progress to date in process democratisation within energy system modelling and planning research.

3.2 Introduction

The focus of energy system modelling and planning has been undergoing a paradigm shift in recent years, whereby assessing the social and political feasibility has become a policy and

research priority. This emanates from a need to build consensus on the best path forward. As (Waisman et al., 2019, p. 262) note, in order for long-term decarbonisation strategies to be implemented they “*must be sufficiently understood and accepted by a working majority of stakeholders, both those responsible for implementation and those affected by the transformation (for example, governments, indigenous peoples’ organizations, sector associations, firms, energy utilities, unions, experts, households and non-governmental organizations)*”.

In relation to climate change, in light of the urgency needed and inertia present, the value of the engaging with a range of stakeholders is quite clear. The inclusion of factors from social sciences, while increasing model complexity and uncertainty, is an important step towards a better understanding of how the systems may be deployed (Pfenninger et al., 2014). Many of the barriers to the development of renewable energy are non-technical challenges that are dynamic and context dependent. In the case of opposition to large-scale wind energy for example, existing research has shown a variety of conditions that shape public perception including physical, contextual, political, economic, social, local and personal aspects (Devine-Wright, 2005). Transcending many of these issues is a lack of trust and openness emanating from a perceived lack of public inclusion in the planning / decision-making process (Knudsen et al., 2015).

Similar to the approach of (von Wirth et al., 2018), this paper conducts a systematic literature review in order to build an understanding of this emergent field. Firstly, to capture the range of existing work in the area, and secondly, to build an understanding of progress to date in democratising the energy system modelling and planning process, by answering the following research questions:

1. What stakeholders have been engaged? Moreover, to what extent has this involved engaging stakeholders outside of energy related fields?
2. To what extent has this involved a collaborative process as opposed to simply a consultation?
3. How have the qualitative outputs from stakeholder engagement been translated for use in quantitative energy system models or assessment tools?
4. What are the challenges and benefits of taking a participatory approach?
5. Within the current body of literature, what are the gaps and subsequent considerations for future research?

As noted by (Mirakyan and De Guio, 2013), due to the fact that energy system modelling and planning crosscuts environmental, social and economic aspects, it thus requires a combination of methods. However, existing literature reviews generally deal with topics separately. Scheller and Bruckner assess how a range of energy system optimization models (ESOMs) may be used for municipal level analysis, but do not discuss the inclusion of local stakeholders in the modelling process (Scheller and Bruckner, 2019). Similarly, Cuesta et al., review a range of tools for designing hybrid renewable energy systems and conclude that these do not consider important social factors (Cuesta et al., 2020). (Ribeiro et al., 2011) provide an overview of methodologies for assessing social impacts in electricity power planning, with only five of the nineteen studies reviewed including participative approaches. Most recently, (Hirt et al., 2020) explore the frameworks available for linking socio-technical theories and energy/climate models, and note that transdisciplinary approaches (seeking non-academic participation) were underrepresented in the reviewed studies. This highlights a clear lack of coverage in the literature on the progress to date in combining energy system modelling and planning with participatory methods.

The paper addresses this gap as follows. Section 3.3 proposes a conceptual framework for understanding what would be considered a meaningful integration of participatory methods, and briefly introduces the systematic review that was carried out. Section 3.4 examines who has been engaged and how this was done. Section 3.4.1 and 3.4.2 highlight what stakeholder groups have been involved to date and then the engagement methods are assessed against a framework to determine the level of collaboration in Section 3.4.3. Section 3.5 provides details on the range of methods used; initially to capture the qualitative stakeholder input, how this was interpreted or translated for the quantitative analysis and reflections on the merits of the different approaches. Finally, Section 3.6 begins by reflecting on the challenges and benefits of pursuing participatory approaches, before reflecting on the progress to date in process democratisation and highlighting some considerations for future research.

3.3 Methodological approach

This section shall introduce the conceptual framing developed to help define what the meaningful integration of participatory approaches into energy system modelling and planning involves, as well as a brief overview of the systematic review conducted.

3.3.1 Conceptual framing

As illustrated in Figure 3-1, in the past, energy policy was generally assessed against the trilemma of cost, environmental impact and security of supply. However, given the need to build consensus on future energy pathways, it has been increasingly recognised that the societal dimension must also be included. This has subsequently prompted a growing interest in participatory or transdisciplinary approaches to energy system modelling and planning. Two of the key drivers behind this growing interest are: firstly, the need to build a broader understanding of the energy transition within socio-political contexts, and secondly, the democratisation of key decision-making processes. On from this, the criteria for understanding progress in this field are:

1. The diversity of inputs and outputs from the research
2. How well these represent the ongoing energy transition
3. Public acceptance of energy policy
4. The extent to which the participatory process has facilitated an open and transparent discussion on the best path forward.

The latter of which is the primary focus of this review.

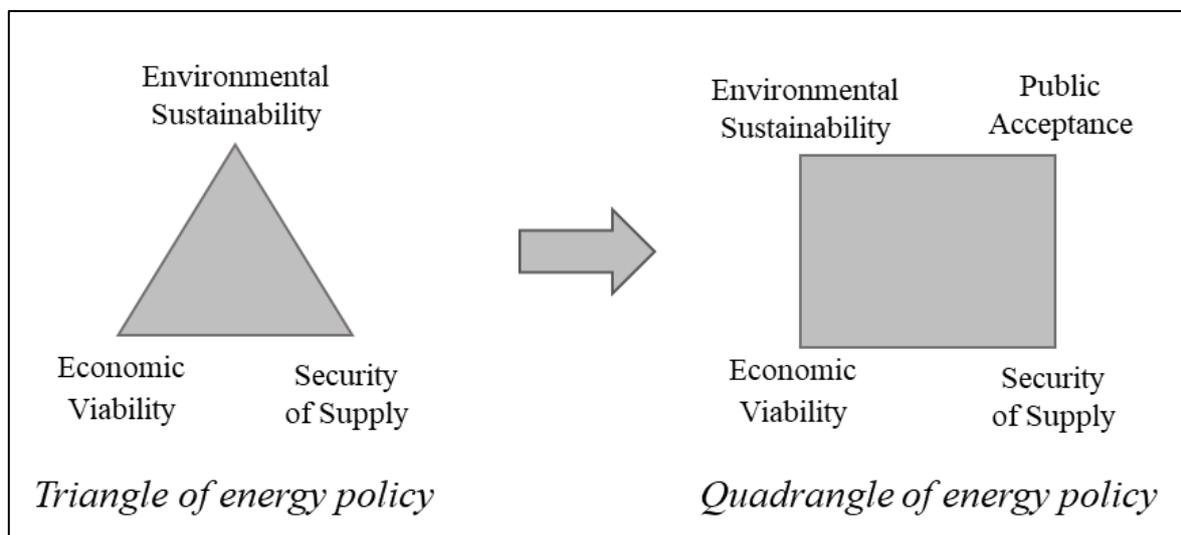


Figure 3-1. Paradigm shift in energy policy (Hauff, 2011) as cited in (Bertsch and Fichtner, 2016).

In order to build an understanding of what process democratisation entails, a conceptual framing was developed. As outlined by (Schubert et al., 2015), in most cases assessing social acceptance involves acceptance of the outcome, i.e. it takes place after the conventional quantitative analysis and is not considered in line with technical and economic factors. Giving

social acceptance equal consideration would be acceptance of the process, established through open and transparent deliberation. Under this framing, we propose that the level of integration can be either shallow or meaningful, as illustrated in Figure 3-2.

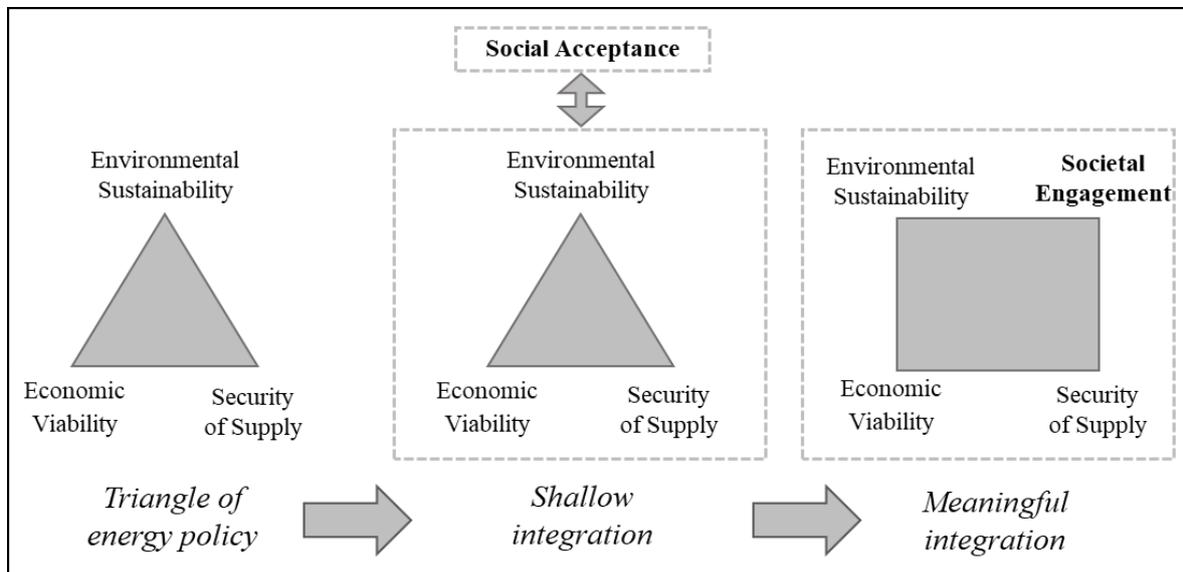


Figure 3-2. The integration of a social dimension into energy policy analysis developed by the authors based on (Schubert et al., 2015).

A shallow integration sees the assessment of social acceptance as an added piece of work separate to the conventional techno-economic analysis performed, whereas a meaningful integration would seek to engage stakeholders throughout the process. There are two common cases of a shallow integration, firstly efforts to incorporate socio-technical theories (such as s-curves, behaviour profiles, etc.) and thus usually only involving academic inter/multi-disciplinary collaborations. Secondly, public attitude surveys that are conducted separately to the energy system analysis and subsequently have no bearing on it. A more meaningful integration that gives the societal dimension an equal weighting to its techno-economic counterparts can be defined as follows:

- As a minimum requirement, the stakeholder input needs to be gathered before performing or drawing conclusions from the quantitative analysis. If the engagement process takes place after the analysis, then key decisions have already been made.
- It should ideally involve an iterative process that allows stakeholders to shape the analysis as well as evaluating the results. In cases where the participants are only involved to frame the analysis or provide insights for it but are not given the opportunity to provide feedback on the results/findings, a lot of the key decision-making is still within the hands of the research team.

- Going further, co-production and collaborative approaches have been recognised as providing an opportunity for academic and non-academic partners to work together in achieving vital sustainability goals (Norström et al., 2020). This involves engaging stakeholders throughout the entire research process, including at early stages during problem structuring and research question framing (Schmid et al., 2011). Thus, maximising the relevance of the analysis being undertaken as it can address real-world problems (DeCarolis et al., 2017). At a national level, the engagement of decision makers can ensure topical policy assessments (Lempert, 2003), while at a local level the public can provide useful ‘social intelligence’ (DeCarolis et al., 2017).

As with many academic concepts, transdisciplinary research has prompted much discussion on its definition (Mullally et al., 2017). This is not a topic for debate within the present review. However, it is important to note that while there is no singular definition of best practice in stakeholder engagement, collaborative/co-production approaches offer useful guiding principles for the democratisation of the process and are thus important in this context.

3.3.2 Systematic review

The full details of the systematic review process are outlined in (McGookin et al., 2021d), and an outlined of the search results is provided in Appendix 1.A. It provided fifty-nine studies for review, which were identified using the following criteria:

- a) Stakeholder preferences, perceptions or opinions had been established through some form of engagement, e.g. interviews, workshops, or meetings
- b) This was a meaningful engagement process (as discussed in Section 3.3.1) and was not purely in the interest of data collection, awareness raising or validation of results. A significant number of studies were excluded as it became clear that the stakeholder engagement took place after the energy system analysis had already been conducted, and thus had no bearing on it.
- c) The output(s) of the engagement were used as input(s) for qualitative or quantitative analysis to inform decisions about future energy system configurations. Studies solely dealing with public attitude surveys toward a particular piece of existing infrastructure were not included.

During the filtering process two clear spatial categories emerged; subnational (or local) and national. In general, the motivation for involving stakeholders differs between the two scalings with national studies focused on policy generation and local geared toward action-orientated

research. These different scalings will require specific approaches and involve different stakeholders so are predominantly addressed separately. One study involved both national and local case studies (Kowalski et al., 2009), which meant that there were a total of twenty-seven studies for review at a national level and thirty-three at the subnational level. A visual representation of the differing spatial and technology focuses can be seen in Figure 3-3. The x-axis relates to the share of the energy system covered. From left to right; a small share with just a single technology focus (e.g. solar PV or bioenergy) to a single or multiple mode (heat, transport or electricity), sectors (e.g. residential) and finally addressing the whole energy system. On the y-axis, the spatial scale goes from top to bottom; national down to regional and then city / town.

It is interesting to note that only twenty-three out of fifty-nine (39%) studies looked at the whole energy system. Roughly one-third (30%) of the national studies had only addressed the electricity system, compared to 15% in the subnational group. Conversely, 27% of subnational studies dealt with only a single technology compared to 7% of national studies. For a full list, see Table 1.B.1 in Appendix 1.B.

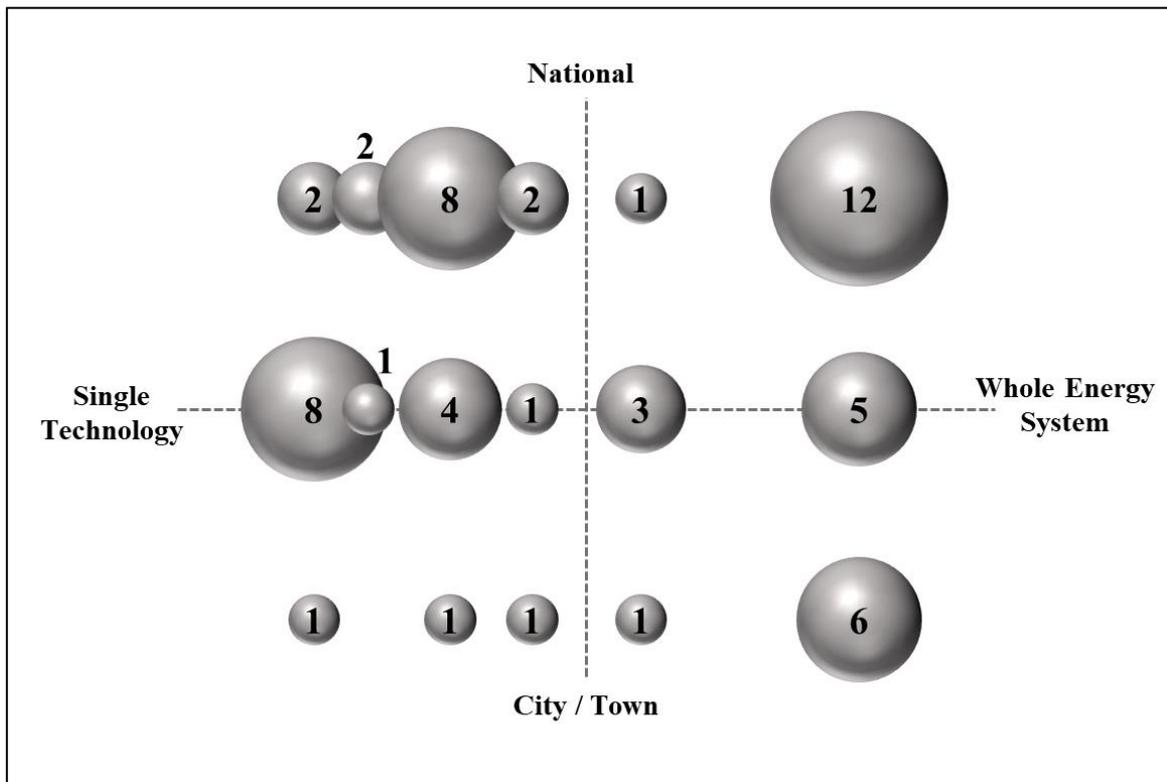


Figure 3-3. Number of studies at the different spatial and technology scales within the papers reviewed.

3.4 Stakeholders Engaged

Figure 3-4 provides a breakdown of the range of stakeholders engaged in the studies reviewed by the share of papers involving each group. Firstly, it looked at the number of studies that had included academic experts. Secondly, the non-academic energy and environment experts involved, primarily coming from government departments responsible for energy policy, actors in the energy market and environmental NGOs or conservation groups. Finally, there was quite a wide range of stakeholders not directly linked to energy and environment issues. The description of participants was generally quite vague, presumably in the interest of anonymity, but still sufficient to categorize them using the adopted framework. A more detailed breakdown can be seen in Appendix 1.B Tables 1.B.2 and 1.B.3.

The number of participants was also recorded to see if there was consensus on what would be a desirable amount. In the subnational studies, very few provided the exact number of participants so no conclusion could be drawn. However, the majority of the national studies provided details on how many participants had been involved. None of them gave explicit justification for the number of participants involved, but having twenty-five participants appears to be the typical amount, with a number of studies having this amount (Zelt et al., 2019), (Fortes et al., 2015), (Schinko et al., 2019), (Madlener et al., 2007) and several others having close to it (Schmid and Knopf, 2012), (Höltinger et al., 2016), (Schmid et al., 2017), (Venturini et al., 2019).

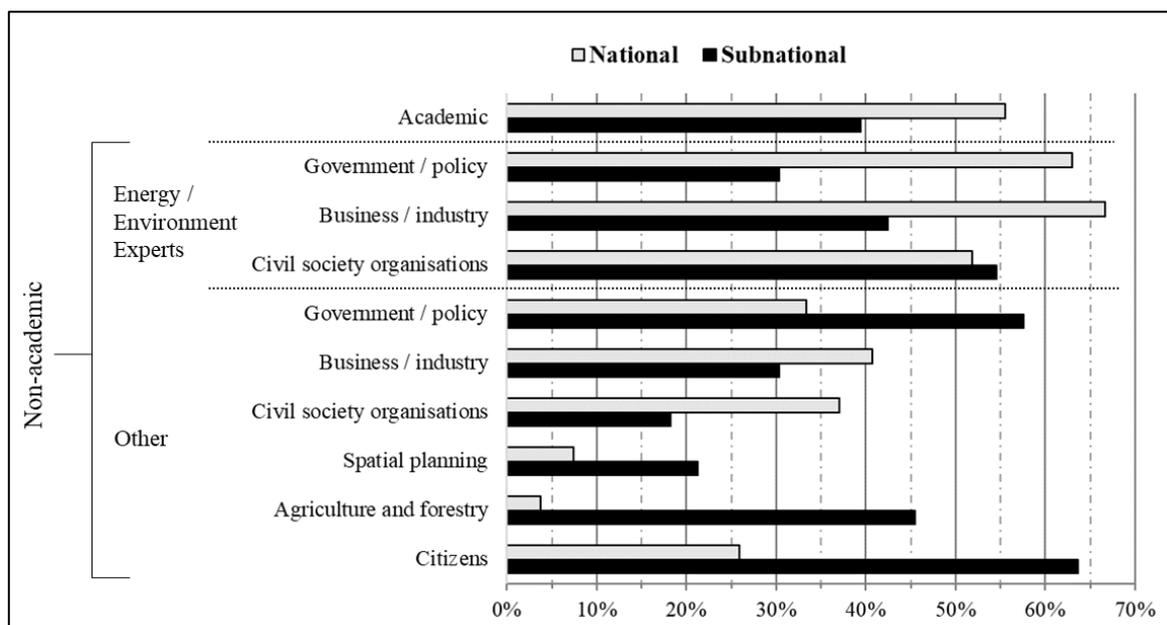


Figure 3-4. Range of different stakeholders by share of papers that involved each group.

3.4.1 Subnational studies

Agriculture and forestry was represented in 45% of subnational studies but only 4% of the national. This was largely due to the rural nature of the regions (McKenna et al., 2018), (Vargas et al., 2018), (Marinakis et al., 2017a), (Terrados et al., 2007), (Trutnevyte et al., 2011), (Düspohl et al., 2012), (Olabisi et al., 2010) or fact the study was investigating the bioenergy resource potential of an area and how it may impact forestry or land-use (Schmuck et al., 2013), (Giannouli et al., 2018), (Busch, 2017), (Dubinsky et al., 2019), (den Herder et al., 2017), (Schmuck, 2012), (Atwell et al., 2011), (Vaidya and Mayer, 2016). This highlights one of the main advantages of working on a smaller scale, which allows for more targeted analysis to understand the area's characteristics. There was also a much larger focus on understanding local perceptions and priorities, with 64% of studies involving members of the public compared to 26% in the national studies. This is perhaps to be expected, as studies focused on local energy systems stand to benefit greatly from tapping into the local knowledge. A number of studies concerned with the development of renewable energy in isolated rural communities worked closely with indigenous (or aboriginal) villagers (Alvial-Palavicino et al., 2011), (Salerno et al., 2010b), (Vargas et al., 2018). In these instances, a key element of the research was building social capital and strengthening relationships with local people in order to build trust and understanding. In the other sixteen studies that had involved citizens there were two predominate motivations. Firstly, to allow local people an opportunity to express their concerns or preferences toward different technology options (McKenna et al., 2018), (Flacke and De Boer, 2017), (Uwasu et al., 2020), (Soria-Lara and Banister, 2018), (Krzywoszynska et al., 2016), (Bessette et al., 2014), (Mayer et al., 2014), (Kowalski et al., 2009), (Marinakis et al., 2017a), (Terrados et al., 2007), (Olabisi et al., 2010), (Schmuck, 2012), (Thomas et al., 2018),. Secondly, to understand the end-user expectations or lived experience of a particular technology (Trutnevyte et al., 2011), (Vaidya and Mayer, 2016), (Zivkovic et al., 2016).

Elected representatives and policymakers (not directly linked to energy or environment) were involved in 60% of the studies, compared to only 33% of the national studies. One interesting point to note is the inclusion of mayors; this suggests a keen interest from the local government given that these top-level officials made themselves available for the time needed to participate in the research (Kowalski et al., 2009), (McKenna et al., 2018), (Trutnevyte et al., 2011), (Schmuck, 2012) (Nabielek et al., 2018), (Bernardo and D'Alessandro, 2019). The inclusion of decision makers in the form of planners and elected officials is important as the energy system modelling and planning process can open up insightful discussions on the trade-offs

and impacts of policy measures. As the development of renewable energy transforms the energy system to a more decentralised platform, governance must do likewise. As noted in Sperling et al., while key elements like infrastructure developments and institutional frameworks (such as building codes) have to be stepped up and managed at a national level, there is increasing need for the involvement of local stakeholders, especially local authorities, in the design and planning process (Sperling et al., 2011).

Only six out of thirty-two studies had no representation from energy or environmental experts. The majority of stakeholders came from energy or environmental related backgrounds, with 85% of studies involving representatives from either the energy industry, government departments, local energy agencies or co-operatives and environmental NGOs. There were, however, some interesting inclusions from outside this field, with a number of studies involving representatives from religious institutions (Olabisi et al., 2010), (Salerno et al., 2010b), (Krzywoszynska et al., 2016), health (Olabisi et al., 2010), education (Marinakis et al., 2017a), (den Herder et al., 2017), tourism (Terrados et al., 2007), (den Herder et al., 2017), (Salerno et al., 2010b), finance (Düspohl et al., 2012), (Giannouli et al., 2018), (Droste-Franke et al., 2020), and construction (Giannouli et al., 2018), (Kowalski et al., 2009). One noticeable omission is civil society organisations not linked to energy or environmental concerns, which featured in just under 20% of studies, with only two noting the involvement of community development organisations. These groups could offer invaluable expertise, with an existing reputation in the area and understanding of its challenges, as well as providing a means of reaching the vulnerable and underrepresented members of the community.

3.4.2 National studies

At a national level, there was a greater emphasis placed on working with energy experts to get a detailed understanding of a particular sector or how different elements of the energy system interact. The research served as a means to facilitate discussion between key actors from the energy industry (appearing in 67%), government/policymakers (63%) and academia (56%). This is not surprising, firstly due to the fact representatives from the energy industry were specifically targeted in order to better understand the energy market, and secondly, given that participation in the process may provide valuable insights for policymakers or utilities and energy suppliers. As noted in a number of studies, the deliberation process can contribute to the formation of more informed and actionable policy (Eker et al., 2018), (Nabielek et al., 2018), (Venturini et al., 2019).

However, the prominence of experts in the national studies could be criticised as failing to provide real-world ‘on the ground’ knowledge, experiences, perceptions and values (Baard, 2021). As with the subnational, only four studies (15%) had no representation from energy or environment experts. These specifically focused on capturing public perceptions (Demski et al., 2017), (Chapman and Pambudi, 2018), (Volken et al., 2018), (Steinberger et al., 2020), through a number of innovative ways, covered in detail in Section 4.1.4. There were five studies that involved a consumer association as oppose to actual customers, perhaps reflecting the need for national studies to take a broader perspective.

3.4.3 Level of participation

There are a number of different frameworks for classifying the level of participation in stakeholder engagement activities. Notably, Arnstein’s ‘ladder of participation’ is a well-known means of classifying stakeholder involvement in the planning system (Arnstein, 1969). The “Public Engagement Onion” developed by Wellcome Trust offers a similar means of classification based on the level of control given to participants (Wellcome Trust, 2011). With regards to energy research, Trutnevyte and Stauffacher during a review of a transdisciplinary research project distinguish between the different activities based on the form of communication and its purpose (Trutnevyte and Stauffacher, 2012). From these the following framework was adopted, comprised of three levels of engagement as follows:

- Informing – one-way flow of communication, usually for the purpose of awareness raising or educating, no opportunity for input into a decision-making process, participants cannot influence the outcome of the research.
- Consulting – two-way flow of communication, surveys, interviews or workshops used to elicit stakeholder opinions, participants have opportunity to shape the research results but not the research questions or objectives.
- Collaborating – open and transparent communication throughout the process, participants given the opportunity to shape research questions and direction throughout the duration of the project.

As outlined in the Introduction, public trust in decision-making processes will be key to the success of energy policy. This requires an open and transparent process that facilitates discussion and debate. In light of this, it is good to see that conducting a workshop or series of workshops stood out as the most common form of engagement undertaken. A number of studies in both of the groups, involved multiple interactions, conducting a semi-structured interviewed

or survey prior to the workshop(s) (Kowalski et al., 2009), (McKenna et al., 2018), (Vargas et al., 2018), (Düspohl et al., 2012), (Olabisi et al., 2010), (Schmuck et al., 2013), (Heaslip and Fahy, 2018), (Noboa et al., 2018), (Steinberger et al., 2020), (Macmillan et al., 2016), (Xexakis et al., 2020), (Eker et al., 2018), (McDowall, 2012), see Section 3.5.1.1.

(Lang et al., 2012) outline that an important step in the formation of a transdisciplinary research project is that a collaborative team of diverse scientific backgrounds and non-academic representatives should design the research. The process of jointly identifying the real-world problem and research objectives helps to ensure the research is correctly orientated and facilitates the building of trust and understanding between the research team and relevant stakeholders. However, there was a limited number of studies indicating a collaborative approach. As can be seen in Figure 5, only ten of the studies reviewed (17%) noted some form of transdisciplinary committee or partnership with non-academic stakeholders (Schmid and Knopf, 2012), (Vargas et al., 2018), (Trutnevte et al., 2011), (Olabisi et al., 2010), (Schmuck et al., 2013) (Giannouli et al., 2018), (Dubinsky et al., 2019), (Atwell et al., 2011), (Zivkovic et al., 2016), (Droste-Franke et al., 2020), with another four mentioning further discussions or meetings outside of the formal engagement process (Kowalski et al., 2009), (Marinakis et al., 2017a), (Soria-Lara and Banister, 2018), (Sharma et al., 2020). Moreover, it is striking to note that in 36% of studies the stakeholder participation involved just one interaction.

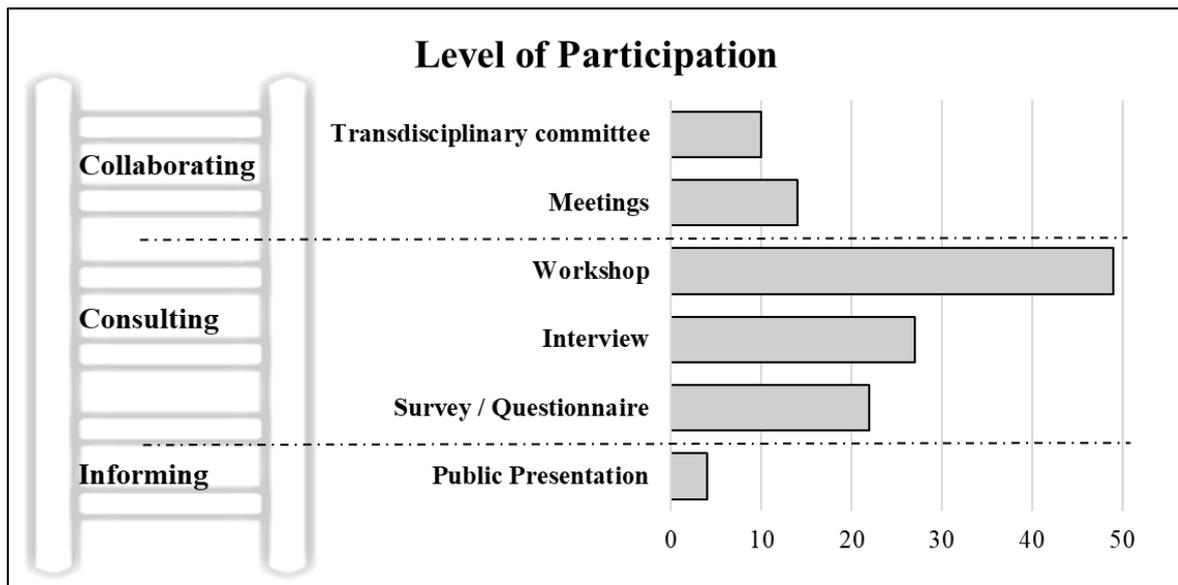


Figure 3-5. Level of stakeholder participation in the papers reviewed.

3.5 Methods Used

This section explores the variety of qualitative and quantitative methods used in the studies reviewed. Firstly, addressing how stakeholders have been engaged as well as the methods used to capture their inputs. Secondly, the quantitative analysis undertaken and how this was shaped by the stakeholder participation. For each of the individual methods a general overview and brief summary of how it was applied in the studies reviewed is provided, noting the linkages between the qualitative and quantitative elements as well as the strengths/weaknesses of the various approaches. Figure 3-6 displays the methods used by the number of studies, for the full list see Appendix 1.B Table 1.B.4. There are a couple of methods not discussed due to the limited number of examples in the literature reviewed, these include agent-based modelling (ABM) (Düspohl et al., 2012), (Michas et al., 2020) and sensitivity analysis (SA) (McKenna et al., 2018), (Marinakakis et al., 2017a).

Stakeholder inputs				
Scenarios, 31	Interview, 27	Survey, 21	Dialogue / deliberation, 13	Cognitive mapping, 9
			Serious games, 12	Visioning / storytelling, 8
Quantitative analysis				
MCDA, 16	Resource assessment, 14	ESOM, 10	Simulation tools, 4	ABM, 2
			SDM, 4	SA, 2

Figure 3-6. Methods used in the papers reviewed by number of studies.

3.5.1 Facilitating stakeholder input

3.5.1.1 Interviews and surveys

Interviews and other surveying techniques were used in a number of different ways. The most common method at both a local and national level was semi-structured interviews, which were conducted in 46% of studies reviewed. This was generally seen as a prerequisite to conducting

a workshop with a diverse group of stakeholders, as it is important to first allow the stakeholders to have the opportunity to individually express their views (Düspohl et al., 2012), (Vaidya and Mayer, 2016), (Alvial-Palavicino et al., 2011), (Soria-Lara and Banister, 2018), (Heaslip and Fahy, 2018), (Noboa et al., 2018). (Macmillan et al., 2016), (Eker et al., 2018), (McDowall, 2012), (AlSabbagh et al., 2017), (Robertson et al., 2017), (Foran et al., 2016). This has the co-benefit of greater stakeholder participation and also gathering useful data for the researchers. The loosely structured nature of semi-structured interviews conducted face-to-face provides a more creative space for discussion, allowing participants to better express their opinions and mitigating against the risk that stakeholder's different views may not be documented when reaching consensus as part of workshop activities. Moreover, it provides a better understanding of potential tensions and synergies by exploring individual motivations or worldviews prior to grouped workshop activities.

At a local level, these interactions were noted as being of particular importance as a means of building trust within a community (Alvial-Palavicino et al., 2011), developing an understanding of the local area (Vargas et al., 2018), (Foran et al., 2016), (Vaidya and Mayer, 2016) and compiling a list of key stakeholders (Dubinsky et al., 2019), (Alvial-Palavicino et al., 2011). Asking interviewees to identify other stakeholders is a commonly used method of recruitment often referred to as a 'snow-balling' technique (McDowall and Eames, 2007).

A number of other studies used a more formal approach, opting for quantitative methods of data recording in the form of surveys and questionnaires (Bertsch and Fichtner, 2016), (Kowalski et al., 2009), (Madlener et al., 2007), (Höltinger et al., 2016), (Schmid et al., 2017), (McKenna et al., 2018), (Marinakis et al., 2017a), (den Herder et al., 2017), (Atwell et al., 2011), (Vaidya and Mayer, 2016), (Alvial-Palavicino et al., 2011), (Ernst et al., 2018), (Volken et al., 2018), (Mathy et al., 2015), (Chapman and Pambudi, 2018). This was generally necessitated by the method being used, although there were a number of different purposes; ranking criteria as a prerequisite for MCDA (Bertsch and Fichtner, 2016), (Kowalski et al., 2009), (Madlener et al., 2007), (McKenna et al., 2018), (Marinakis et al., 2017a), (den Herder et al., 2017), (Atwell et al., 2011), (Vaidya and Mayer, 2016), (McDowall and Eames, 2007), ranking options using a Likert scale (Schmid and Knopf, 2012), (Xexakis et al., 2020), (Volken et al., 2018), (Chapman and Pambudi, 2018), (Jeong, 2018), general opinion surveys (Höltinger et al., 2016), (Schmid et al., 2017), (Atwell et al., 2011), (Ernst et al., 2018), (Volken et al., 2018), (Mathy et al., 2015), (Chapman and Pambudi, 2018), data gathering (Simoes et al., 2019) and evaluation (Alvial-Palavicino et al., 2011), (Ernst et al., 2018), (Volken et al., 2018).

The means by which the surveys were conducted varied from; face-to-face interactions as part of a workshop (Atwell et al., 2011), (Xexakis et al., 2020), (Volken et al., 2018), (Mathy et al., 2015), or structured interview (Bertsch and Fichtner, 2016), (Kowalski et al., 2009), (Madlener et al., 2007), (McKenna et al., 2018), (Atwell et al., 2011), (Alvial-Palavicino et al., 2011), (McDowall and Eames, 2007), (Simoes et al., 2019), telephone interview (Schmid et al., 2017) and online surveys (Bertsch and Fichtner, 2016), (Höltinger et al., 2016), (Marinakakis et al., 2017a), (den Herder et al., 2017), (Vaidya and Mayer, 2016), (Ernst et al., 2018), (Volken et al., 2018), (Chapman and Pambudi, 2018). In a couple of cases the survey was the only form of participation from the public, and the results of the surveys were then discussed in ‘expert’ workshops (Bertsch and Fichtner, 2016), (Chapman and Pambudi, 2018).

The trade-off between interviews and surveys is quite clear. Interviews can provide descriptive data that is useful for getting a deeper understanding of stakeholders differing perspectives, which is by its nature difficult to integrate into energy system models. While surveys can provide quantitative data that may be more easily integrated into the models but fail to provide any context. For example, in an interview someone could explain the complex variety of reasons for disliking a particular technology but in a survey this may be greatly oversimplified as technology X is less popular than technology Y.

3.5.1.2 Scenario generation

The generation of scenarios, narratives or pathways based on stakeholder input or dialogue was another common form of qualitative analysis appearing in 53% of studies. This is not surprising considering how widely used scenarios are as a tool in long term energy system modelling (Prasad et al., 2014b). Scenarios are an effective way to specify future visions and are particularly useful for exploring highly complex and uncertain systems.

An important methodological feature in the formation of scenarios is the use of a set of assumptions about key relationships and drivers of change within a system based on historical trends or the current state. In energy system modelling there are two forms of scenarios: descriptive storylines and quantitative projections. The process generally involves establishing narratives for the future before generating projections of economic and technical parameters like expected growth, resource potential, cost of technologies, etc. Linking qualitative storylines and quantitative elements in this manner improves our understanding of how systems work and evolve, which can provide useful insights on the synergies and trade-offs between different policy options (Venturini et al., 2019), (Busch, 2017), (Salerno et al., 2010b).

Adopting a participatory approach to scenario development can broaden the boundary of analysis into the socio-political context within which the system will be built, providing a platform for the discussion of key trends and drivers with relevant actors. The sharing of real-world knowledge about the deployment of technologies, ensures that all major uncertainties and different perspectives of stakeholders are taken into account (Düspohl et al., 2012). For those involved, this helps to identify areas of common interests, (Busch, 2017) while also encouraging practical learning both of energy systems and also creative ways to think about the future (Düspohl et al., 2012), (Uwasu et al., 2020).

Focusing on how scenarios were used within the studies reviewed, in the subnational group it was found that the majority of local studies had either solely involved stakeholders for the purpose of explorative scenario generation (Düspohl et al., 2012), (Busch, 2017), (Salerno et al., 2010b), (Uwasu et al., 2020), (Zivkovic et al., 2016), or agreeing desired outcomes (Kowalski et al., 2009), (Olabisi et al., 2010). The priority was to develop a shared vision or objective. By contrast, the national studies gave greater consideration to the scenario descriptions, prioritising the discussion of trends and drivers with participants. Primarily involving experts from the energy industry, dialogue through interviews or workshops sought to capture the range of perspectives on market trends that would impact the rate of the deployment of specific technologies (McDowall, 2012) or changes within certain sectors (Schinko et al., 2019), (Venturini et al., 2019), (AlSabbagh et al., 2017). The emphasis was placed on building consensus and understanding between researchers, government and industry stakeholders in order to develop better aligned pathways and policy recommendations for decarbonisation targets.

3.5.1.3 Cognitive Mapping

Cognitive maps also referred to as mental maps or mental models are a commonly used method of problem structuring or framing. They are effective tools for conceptualising a system and its causal relationships, which makes them useful for identifying values and choices amongst a diverse network (Eden, 1988). They come in a variety of different forms causal loop diagrams (Olabisi et al., 2010), perception graphs (Düspohl et al., 2012) or logic trees (Uwasu et al., 2020). A cognitive map is the representation of a problem through the development of a network of nodes and arrows, whereby the links depicted by arrows denote a perceived causal relationship (Eden, 2004). The objective of this approach is to identify the interactions among variables and the structure of feedback loops, providing a clearer understanding of the cause-

effect relationships within a complex system. Given that energy policy is a highly complex and multi-faceted ‘wicked’ problem, the use of a problem structuring method is warranted.

Within the literature reviewed, the primary use of cognitive maps, across local and national studies, was to capture and conceptualize individual stakeholder’s perceptions of the dynamics and interactions within challenging and potentially controversial issues like bioenergy (Düspohl et al., 2012), (Olabisi et al., 2010), (Salerno et al., 2010b) and housing (Macmillan et al., 2016), (Eker et al., 2018). This was done by first interviewing stakeholders in order to understand the perceptions of the individual actors, before merging them as part of a workshop in order to form an agreed model of the system under investigation (Düspohl et al., 2012), (Olabisi et al., 2010), (Salerno et al., 2010b), (Macmillan et al., 2016), (Eker et al., 2018). In one other study, assessing the social and economic impacts of the policies adopted across the whole energy system within a city, the causal loop diagrams were developed over the course of two workshops and did not involve any interviews (Bernardo and D’Alessandro, 2019). Another made use of a logic tree to map out and explore how proposals made over a series of workshops would contribute to the different energy visions (Uwasu et al., 2020).

This provides a holistic view of the system and its causal relationships, which can open up useful insights into the knock-effects and trade-offs of different policy measures, as well as an important understanding of interdependencies within the system. In doing so, facilitating a broader discussion around the social and environmental impacts of policy. For example, in the case of bioenergy giving consideration to issues around land use and forestry, and in the case of housing capturing the health and wellbeing benefits of improved energy efficiency.

The majority of studies used the developed causal loop diagrams as a basis to perform system dynamics modelling (Olabisi et al., 2010), (Salerno et al., 2010b), (Bernardo and D’Alessandro, 2019), (Eker et al., 2018). This is covered in Section 3.5.2.3. However, in two cases the analysis was purely qualitative, establishing a framework and set of criteria for exploring future policies but not demonstrating its use within the study (Düspohl et al., 2012), (Macmillan et al., 2016). In one instance, Macmillan et al.’s work (Macmillan et al., 2016) is what formed the basis for that undertaken by Eker et al., involving the same stakeholder groups at different stages of the model development process (Eker et al., 2018).

A very similar concept to the use of cognitive mapping is mind mapping. In one study, it was used during the first workshop to capture general expectations for the research such as desires for community involvement, objectives and technical options that should be explored

(McKenna et al., 2018). In the other study, researchers performed a stakeholder mapping exercise prior to the engagement process in order to group actors in terms of their importance for planning within the region, as well as highlight potential synergies or conflicts (Giannouli et al., 2018).

3.5.1.4 Serious Games

A serious game is an interactive approach that is designed with the intention to teach rather than purely entertain. They often involve imagining alternative realities that can facilitate interesting discussions on complex real-world problems with a diverse group of stakeholders. The use of serious games in climate change research is well documented (Flood et al., 2018), (Crookall, 2013), (Reckien and Eisenack, 2013). These games can help raise awareness, build capacity for problem solving and provide a useful space to explore complex problems (Eisenack and Reckien, 2013). Serious games are likewise suitable for exploring the challenges associated with energy system modelling and planning. In contrast to the other methods discussed throughout Section 4, which noted ways of combining the use of qualitative and quantitative analysis, this approach offers a means of merging the two by giving stakeholders tools to see in real-time their energy system configurations and the associated reduction in emissions or spatial trade-offs, etc. However, this comes at the cost of greatly simplifying energy system characteristics or the results of existing energy system models (Xexakis et al., 2020), (Steinberger et al., 2020).

The studies reviewed provided a number of different approaches to develop energy portfolios through the use of; maps (Krzywoszynska et al., 2016), (Nabielek et al., 2018), (Steinberger et al., 2020) role-playing (Thomas et al., 2018) and computer tools (Flacke and De Boer, 2017), (Uwasu et al., 2020), (Bessette et al., 2014), (Mayer et al., 2014), (Steinberger et al., 2020), (Xexakis et al., 2020), (Volken et al., 2018), (Demska et al., 2017). At a local level, maps were used in a number of different ways to develop portfolios to meet a region's energy demand (Krzywoszynska et al., 2016), (Thomas et al., 2018), (Nabielek et al., 2018). One study used a cardboard game approach, pinning pieces of card scaled based on a technology's delivered kWh/m²/annum onto a map of the area detailing general information on topography and land use (Nabielek et al., 2018). In addition, participants were given a booklet containing background information with regard to the existing energy facilities, energy consumption, and renewable energy potentials. Another study used an aerial photograph to identify potential sites for renewable development and modelled a number of different scenarios before producing a

scale model of the desired option through a number of interactions between architecture students and the local residents (Krzywoszynska et al., 2016). Another example from Switzerland used the combination of a computer-based portfolio selection tool and map-based board game to initially gather preferences and then discuss spatial issues of actually placing the technologies (Steinberger et al., 2020). Similar to these approaches was the use of energy proposal cards for a fictional town, providing information around plant siting and attributes like the new plants contribution to jobs and climate targets (Thomas et al., 2018). Participants were then asked to assume the role of local decision makers (in the form of ‘town councillors’ or ‘council members’) and rank the proposals as a group.

Interactive computer tools were used at both a subnational and national level, examining portfolios of the whole energy system (Uwasu et al., 2020), (Demski et al., 2017) or just electricity (Bessette et al., 2014), (Mayer et al., 2014), (Droste-Franke et al., 2020), (Steinberger et al., 2020), (Xexakis et al., 2020), (Volken et al., 2018). The general framework applied was to provide members of the public with information on different renewable energy technologies and then ask them to choose a portfolio of technologies to meet a particular energy or electricity demand. This was done both with and without facilitation; two studies relied on people doing it by themselves (Demski et al., 2017), (Mayer et al., 2014), while the others worked during workshop sessions (Uwasu et al., 2020), (Bessette et al., 2014), (Droste-Franke et al., 2020), (Xexakis et al., 2020), (Volken et al., 2018). (Flacke and De Boer, 2017) combined the use of maps and a computer tool using a digital 3D map/visualisation on a tabletop display.

The dashboard or interface differed according to the approach being used. One of the studies involved a web-based tool that allowed users to explore their preferences towards different supply and demand options by displaying the changes on an animation at the level of home, city and country (Demski et al., 2017). After making adjustments to achieve a CO₂ reduction target, users had the option to submit their scenario to a research database. The other studies involved using a dashboard to select an electricity portfolio, which came in the form of a simplified excel representation downloaded from an online portal (Bessette et al., 2014), (Mayer et al., 2014) or was provided during a workshop session (Schinko et al., 2019), (Xexakis et al., 2020), (Volken et al., 2018). One study provided a CO₂ simulator for assessing the range of proposals put forward during the workshops (Uwasu et al., 2020). In another interesting example, (Droste-Franke et al., 2020) developed a web application of the tool that had been used to assess scenarios during a workshop so that it could be further disseminated.

The information provided to users or participants likewise differed based on the approach. The primary focus was on CO₂ emissions; however, one dashboard also displayed the impact of chosen technologies on land, water and health (Mayer et al., 2014). Two of the studies chose to have information on technology impacts provided in the factsheets (Uwasu et al., 2020), (Xexakis et al., 2020), (Volken et al., 2018). This was done to avoid distorting participants view and allow them to individually assess the importance of environmental, health, or economic impacts. In an interesting example, (Xexakis et al., 2020) compared the difference between ‘informed’ citizens given factsheets and a sample that hadn’t been provided them.

3.5.2 Quantitative Analysis

3.5.2.1 Simulation and Optimization Tools

The two prominent forms of energy system models are optimization and simulation tools. Optimization models solve for the least cost solution to satisfy energy service demands under set constraints like the cost of technologies and predictions for when they will become available. On the other hand, simulation models generate projections of the energy demand / supply based on user-defined assumptions like the share of energy supply options, the level of economic activity and energy intensity of different sectors.

This was the most common form of quantitative analysis in the national studies, with 67% of studies (using an optimization tool, and in particular MARKAL / TIMES (Fortes et al., 2015), (Venturini et al., 2019), (McDowall, 2012), (Sharma et al., 2020), (Chapman and Pambudi, 2018). Others used in-house models such as REMIND-D (Schmid and Knopf, 2012), MOTRiP (Robertson et al., 2017) and Imaclim-R-France (Mathy et al., 2015), or simulation models such as renpassG!S (Zelt et al., 2019), (Schinko et al., 2019) and LEAP (AlSabbagh et al., 2017). One example from Germany used a direct current (DC) electricity grid expansion tool within PERSEUS-NET (Bertsch and Fichtner, 2016). By contrast, in the subnational studies this was the least utilized method, with only five examples (15% of studies reviewed). Two made use of optimization models TIMES (Simoës et al., 2019) and RE³ASON (McKenna et al., 2018), while one other example used LEAP (Zivkovic et al., 2016). In designing a microgrid system for remote rural communities, another couple of examples used the HOMER-PRO Energy software (Vargas et al., 2018), (Heaslip and Fahy, 2018).

Across national and subnational studies, the use of simulation and optimization models generally involved a three stage process as follows; i) the development of socio-economic storylines or narratives based on stakeholder workshops or interviews, ii) the translation of

these qualitative scenarios into quantitative modelling assumptions, iii) the development and assessment of quantitative energy scenarios (Fortes et al., 2015).

The means of capturing stakeholder's vision for the future and technology preferences varied from solely involving a survey (Schinko et al., 2019), (Chapman and Pambudi, 2018) or interview (AlSabbagh et al., 2017), a combination of interviews (or survey) and a workshop (Schmid and Knopf, 2012), (McDowall, 2012), (Robertson et al., 2017), (Mathy et al., 2015), a once-off workshop (Zelt et al., 2019), (Fortes et al., 2015), (McKenna et al., 2018), (Sharma et al., 2020), and being developed in a series of workshops (Venturini et al., 2019), (Zivkovic et al., 2016), (Simoes et al., 2019). In the majority of cases there was no further engagement with the stakeholders, the research team carried out the translation of the stakeholder inputs into model parameters without any form of evaluation or feedback. Only three studies involved an iterative process whereby the models were revised following a feedback session (Venturini et al., 2019), (Zivkovic et al., 2016), (Simoes et al., 2019). Venturini et al., were the only study that explored the underlying modelling assumptions with the stakeholders involved (Venturini et al., 2019). In another interesting example, Schmid et al. held a session to discuss the modelling results and the socio-political implications of the different scenarios that had been developed (Schmid and Knopf, 2012). While Sharma et al. did not hold a dedicated feedback session with the participants, it is noted that during the development of a scenario ensemble based on these inputs there was an ongoing discussion with key policy advisers (Sharma et al., 2020). Four other studies assessed the modelling outputs using an MCDA method, which was determined during the scenario-building workshop or as part of a dedicated follow-up meeting (Zelt et al., 2019), (Schinko et al., 2019), (McKenna et al., 2018), (Simoes et al., 2019).

3.5.2.2 Multi-Criteria Decision Analysis

Within the literature reviewed, there are a number of reviews available on the use of multi-criteria decision analysis (MCDA) in energy planning and decision-making (McKenna et al., 2018), (Marinakos et al., 2017a), (den Herder et al., 2017). These provide a detailed overview of MCDA methods, but lack a key focus on the participatory element, which will be covered in this subsection. The name 'multi-criteria decision analysis' was the most commonly used, and thus is used here to also refer to the range of alternatives that appeared within the literature reviewed; multi-criteria assessment (Kowalski et al., 2009), (Trutnevyte et al., 2011), multi-objective decision-making (Busch, 2017) and multi-criteria mapping (McDowall and Eames, 2007).

MCDA is a tool for determining the weighted importance of a range of criteria or indicators. It is popular within energy system analysis due to its ability to highlight trade-offs and interconnectedness between a variety of different social, economic, technical, and environmental factors. With regards to taking a participatory approach, the most relevant part is how the criteria were chosen and weightings were determined. In half of the studies reviewed, participants only inputted into the weightings while the researchers chose the criteria based on experience, a review of the literature or policy documents (Bertsch and Fichtner, 2016), (Marinakos et al., 2017a), (Trutnevyte et al., 2011), (Busch, 2017), (den Herder et al., 2017), (Droste-Franke et al., 2020), (Jeong, 2018). To evaluate their choice, one study asked participants if they felt any indicators were missing (Jeong, 2018).

In the remaining studies, participants were included in the criteria selection, assessment and weighting process through a range of approaches (Kowalski et al., 2009), (Zelt et al., 2019), (McKenna et al., 2018), (Trutnevyte et al., 2011), (Vaidya and Mayer, 2016), (McDowall and Eames, 2007), (Simoes et al., 2019). (Trutnevyte et al., 2011) decided the relevant criteria in discussions with the transdisciplinary committee set up to oversee the research and several representatives from the energy industry. (Kowalski et al., 2009) in two separate case studies, at national level did this solely through individual interviews and in the two local areas through reaching a group consensus in facilitated workshops. (Vaidya and Mayer, 2016) used focus groups and interviews before narrowing the list of criteria and determining weightings in a workshop. (Zelt et al., 2019) gathered the criteria from surveys conducted with the relevant stakeholders, and then determined individual weighting before asking participants to join one of these four groups: techno-economic, societal, environmental, or equal preference. Similarly, (Simoes et al., 2019) agreed criteria in a group discussion, then asked participants to individually weight them before coming together to reach a group consensus. (McDowall and Eames, 2007) made use of the multi-criteria mapping software during an interview to take participants through the entire process. (McKenna et al., 2018) as part of a workshop, used a mind map initially to capture the community's values and objectives before discussing the criteria to be explored.

3.5.2.3 System Dynamics Modelling

System dynamics modelling involves mapping out the relationships between a system's various elements and defining them with a series of non-linear equations (Eker et al., 2018). It follows the growth or decrease of a series of variables over time referred to as 'stocks' and the

rate at which they change referred to as ‘flows’. The involvement of a diverse group of stakeholders in the model development process through approaches like cognitive mapping (as in Section 3.5.1.3) strengthens the underlying assumptions governing the model such as model variables, causal relationships and parameter values. This supports model validation as well as shared learning amongst the participants about the complexity and deeply interconnected nature of the energy system (Olabisi et al., 2010).

In the literature reviewed, system dynamics modelling was chosen because of its emphasis on causal relationships and whole-systems perspective (Olabisi et al., 2010), (Salerno et al., 2010b), (Bernardo and D’Alessandro, 2019), (Eker et al., 2018). This makes it well suited to exploring the impact of policies on a system’s behaviour. The strength of system dynamics models is their ability to demonstrate unexpected behaviour resulting from a system’s structure across an integrated network of social, technical, and economic elements (Olabisi et al., 2010), (Eker et al., 2018). There are a number of software packages available to develop system dynamics models, such as VENSIM (Bernardo and D’Alessandro, 2019), (Carnohan et al., 2016) or Simile (Salerno et al., 2010a), although one study opted for a simple Excel representation (Olabisi et al., 2010). This was justified as a matter of preference for ease of database handling and linking with the graphical tools used to display the model output.

3.5.2.4 Resource Assessment

In the subnational studies, the most common quantitative analysis undertaken was a resource assessment (Kowalski et al., 2009), (Terrados et al., 2007), (Trutnevyte et al., 2011), (Busch, 2017), (Dubinsky et al., 2019), (Schmuck, 2012), (Krzywoszynska et al., 2016), (Nabielek et al., 2018), (Jeong, 2018). Studies that focused on a single technology such as Solar PV or bioenergy analysed the potential for that particular resource in the area (Busch, 2017), (Dubinsky et al., 2019), (Schmuck, 2012), (Salerno et al., 2010b), (Jeong, 2018). This would perhaps be expected as it will produce usable research outputs for the local communities involved, giving them a valuable insight into the renewable energy resource they are interested in developing. The stakeholder preferences were gathered through a variety of means; surveys / interviews (Jeong, 2018), (Schmuck, 2012), workshops (Terrados et al., 2007), (Busch, 2017), (Krzywoszynska et al., 2016), (Nabielek et al., 2018), combination of interviews and workshops (Kowalski et al., 2009) or interviews and discussion with project steering committee (or community advisory board) (Trutnevyte et al., 2011), (Dubinsky et al., 2019).

Studies working with an MCDA approach generated simplified quantitative energy scenarios covering only energy demand and renewable energy share for a given year (Kowalski et al., 2009), (Trutnevyte et al., 2011). Terrados et al., created a SWOT matrix for a range of renewable energy technologies before deciding on renewable energy objectives (Terrados et al., 2007). Nabielek et al., assessed the feasibility of locations chosen for development through a serious game approach as discussed in Section 3.5.1.4 (Nabielek et al., 2018). In another interesting example, (Krzywoszynska et al., 2016) prepared for the local town a useful and easy to understand infographic highlighting three potential renewable electricity scenarios and what share of local electricity use this would be as well as an estimated payback period.

There were only two examples in the national studies (Kowalski et al., 2009), (Höltinger et al., 2016). Focusing solely on wind energy development, (Höltinger et al., 2016) assessed the technical feasibility and economic viability of four potential development scenarios covering: min, med, max and suitability zones. (Kowalski et al., 2009) in one national study and two local case studies, made projections for the future energy demand and share of renewables based on existing government reports.

3.6 Discussion

3.6.1 Benefits

3.6.1.1 Legitimacy and robustness

The most commonly noted benefit of taking a participative approach was that this would improve the legitimacy and robustness of results (Kowalski et al., 2009), (Fortes et al., 2015), (Schinko et al., 2019), (Schmid and Knopf, 2012), (Höltinger et al., 2016), (Schmid et al., 2017), (Venturini et al., 2019), (Vargas et al., 2018), (Olabisi et al., 2010), (Dubinsky et al., 2019), (Atwell et al., 2011), (Salerno et al., 2010b), (Uwasu et al., 2020), (Soria-Lara and Banister, 2018), (Krzywoszynska et al., 2016), (Thomas et al., 2018), (Zivkovic et al., 2016), (Nabielek et al., 2018), (Bernardo and D'Alessandro, 2019), (Eker et al., 2018), (McDowall, 2012), (AlSabbagh et al., 2017), (Ernst et al., 2018), (Mathy et al., 2015), (Sharmina, 2017), (Moallemi and Malekpour, 2018). As noted earlier, energy transition dynamics go beyond solely techno-economic representations and are more accurately described as systems placed within socio-political contexts. However, most energy system models solely focused on producing technical details, often neglect the interaction between social, political, economic, and technological factors (Fortes et al., 2015). This has led to attempts at combining

quantitative energy system models and qualitative scenarios or storylines detailing socio-technical transitions (Pfenninger et al., 2014), (Li et al., 2015). From this, the field of participatory modelling emerges as an approach that can facilitate understanding in problem framing and thus increase the legitimacy and robustness of the resulting model (Holtz et al., 2015).

The value of the participatory approach is that it allows for discussion of the socio-political implications of different technology options, and thus can include the diverse perceptions, values, assumptions, expertise and experiences of actors (Fortes et al., 2015), (Schinko et al., 2019), (Schmid and Knopf, 2012), (Venturini et al., 2019), (Atwell et al., 2011), (Salerno et al., 2010b), (Krzywoszynska et al., 2016), (Nabielek et al., 2018), (Mathy et al., 2015), (Moallemi and Malekpour, 2018). This facilitates the production of broader knowledge and richer hypotheses (Nabielek et al., 2018), (Eker et al., 2018), (McDowall, 2012), (Ernst et al., 2018), (Mathy et al., 2015) as well as helping bridge the gap between abstract global challenges and local realities, (Schmid and Knopf, 2012), (Vargas et al., 2018), (AlSabbagh et al., 2017), (Kowalski et al., 2009), (Thomas et al., 2018) making solutions more practically applicable (Höltinger et al., 2016), (Soria-Lara and Banister, 2018), (Bernardo and D'Alessandro, 2019). Within the subnational studies reviewed, this was particularly important in tailoring the research to address the issues of concern to the community and building on local knowledge (Nabielek et al., 2018), (Uwasu et al., 2020), (Salerno et al., 2010b), (Dubinsky et al., 2019), (Bernardo and D'Alessandro, 2019), (Atwell et al., 2011).

Given the significance of the societal transition required makes clear the necessity for deliberation and debate as a democratic right of the citizens involved. The deliberative process provides an important opportunity for stakeholders to be included in decision-making (Schmid et al., 2017), (Sharmina, 2017), (Schmuck, 2012), (Thomas et al., 2018). Making underlying modelling assumptions more transparent and having an open discussion on the advantages/disadvantages of different renewable energy options builds public trust (Zelt et al., 2019). This encourages discussion of key drivers of change and trade-offs among different decisions, which leads to solutions that are more socially and politically feasible (Salerno et al., 2010b), (Zivkovic et al., 2016), (Venturini et al., 2019), (Schinko et al., 2019), (Eker et al., 2018), (Olabisi et al., 2010). As noted by (Schmid and Knopf, 2012, p. 671); *“the transformation towards a low-carbon energy system constitute as much a societal effort as an engineer’s project”*.

3.6.1.2 Capacity building through mutual learning

The contribution of the research to social capital and learning was discussed in a variety of different ways, with mutual learning being the most commonly noted (McKenna et al., 2018), (Flacke and De Boer, 2017), (Krzywoszynska et al., 2016), (Heaslip and Fahy, 2018), (Steinberger et al., 2020), (Zivkovic et al., 2016), (Simoës et al., 2019), (Venturini et al., 2019), (Mathy et al., 2015), (Trutnevyte et al., 2011), (Kowalski et al., 2009), (Düspohl et al., 2012). Broadening the scope of the research through participatory methods provides researchers and other actors a valuable understanding of the complex socio-political interactions shaping the diffusion of new technologies as well as educating and supporting the actors involved in their deployment. Deliberations provide an important space for people to learn from each other.

On an individual level, participation in the debate and discussion raises awareness of contemporary sustainability challenges, highlighting the complexity of the problems and potential solutions amongst decision-makers and other stakeholders, (McKenna et al., 2018), (Venturini et al., 2019), (Marinakis et al., 2017a), (Busch, 2017), (Flacke and De Boer, 2017), (Nabielek et al., 2018), (Heaslip and Fahy, 2018), (Steinberger et al., 2020), (Eker et al., 2018), (Volken et al., 2018). This is beneficial in a number of different ways. It gives farmers an opportunity to learn about the potential for income diversification (Busch, 2017). For researchers, working as part of a diverse trans or multi-disciplinary team deepens understanding and improves individual capacity for problem solving (Terrados et al., 2007), (Robertson et al., 2017). Policymakers, by gaining a better understanding of energy issues and policy options, can make more informed decisions (Venturini et al., 2019), (Nabielek et al., 2018).

On a community level, a further benefit of the research project was facilitating the formation of new social networks and the strengthening of relationships between various stakeholder groups (Vargas et al., 2018), (Busch, 2017), (Krzywoszynska et al., 2016), (Zivkovic et al., 2016), (Nabielek et al., 2018), (Foran et al., 2016). During the evaluation of one study, participants identified that a key benefit of the process was “*meeting like-minded people*” (Krzywoszynska et al., 2016, p. 812). In addition to the formation of important networks is the transfer of knowledge and strengthening of local decision-making (Trutnevyte et al., 2011), (Dubinsky et al., 2019), (Eker et al., 2018).

Key to the strengthening of decision-making both locally and nationally was the insight into systems thinking and trade-offs or cause-effect relationships that participants gained from the

methods used in studies (Kowalski et al., 2009), (Venturini et al., 2019), (McKenna et al., 2018), (Trutnevyte et al., 2011), (Düspohl et al., 2012), (Nabielek et al., 2018), (Steinberger et al., 2020), (Simoes et al., 2019). MCDA was noted as a particularly effective tool for enhancing decision-making capacity, through interaction with the method identifying criteria and allocating weightings in order to capture an area's priorities (McKenna et al., 2018), (Trutnevyte et al., 2011), (Simoes et al., 2019). In addition to this, the process of identifying the relevant drivers and cause-effect relationships is a useful learning process (Venturini et al., 2019), (Trutnevyte et al., 2011). Scenarios provide a useful means of exploring potential drivers of energy system transformation and conflicting objectives (Venturini et al., 2019), (Kowalski et al., 2009). While cognitive mapping improves stakeholder's system knowledge and the complexity of interactions (Düspohl et al., 2012).

3.6.1.3 Consensus building and shared ownership of results

The role of researchers as objective and impartial observers was noted as important to provide a platform for controversial discussion and facilitating mediation between diverse stakeholders (Bertsch and Fichtner, 2016), (Kowalski et al., 2009), (Olabisi et al., 2010), (Busch, 2017), (Schmuck, 2012), (Soria-Lara and Banister, 2018), (Krzywoszynska et al., 2016), (Mathy et al., 2015), (Foran et al., 2016). In several studies, one of the key parts of the research project was to break down barriers in a complex negotiation process between conflicting groups (Busch, 2017), (Soria-Lara and Banister, 2018), (Kowalski et al., 2009), (Schmuck, 2012). The creation of jointly owned solutions through debate and collective learning was considered to be an effective means of building trust (Bertsch and Fichtner, 2016), (Olabisi et al., 2010), (Flacke and De Boer, 2017), (Krzywoszynska et al., 2016), (Foran et al., 2016), (Mathy et al., 2015).

The value of building consensus in this manner is a shared ownership of the process and co-created results (Kowalski et al., 2009), (Höltlinger et al., 2016), (Trutnevyte et al., 2011), (Atwell et al., 2011), (Krzywoszynska et al., 2016), (Eker et al., 2018), (Mathy et al., 2015), (Foran et al., 2016). Stakeholders gain a better appreciation of alternative opinions and the interdependences among decisions (Eker et al., 2018), (Foran et al., 2016). As noted previously, this enhances the robustness and legitimacy of results contributing to the potential for real-world change. This is nicely summarized by a Mayor who took part in one of the studies: *“The case study was very helpful in initiating discussions and raising awareness on energy issues in*

our community. It strongly helped us to build the necessary consensus to implement further activities in this sector” (Trutnevyte et al., 2011, p. 7894).

In the national level studies, the creation of more informed or improved policymaking was widely noted (Schinko et al., 2019), (Madlener et al., 2007), (Venturini et al., 2019), (Marinakis et al., 2017a), (Salerno et al., 2010b), (Macmillan et al., 2016), (AlSabbagh et al., 2017). Involving stakeholders during both problem scoping and analysis ensures that suggestions are relevant to policy and management (Salerno et al., 2010b). Engaging private and public stakeholders in the decision-making process makes the set of recommendations more actionable (Marinakis et al., 2017a) (Giannouli et al., 2018), (den Herder et al., 2017), (Simoes et al., 2019). In both groupings, a number of studies highlighted the increase in efficacy for real-world change and stakeholder’s commitment to implementing agreed decisions (Marinakis et al., 2017a), (Atwell et al., 2011), (Zivkovic et al., 2016), (Simoes et al., 2019).

3.6.2 Challenges

3.6.2.1 Dealing with complexity and transparency

The combination of qualitative and quantitative methods is essential to shift energy system modelling and planning away from an exclusive focus on techno-economic uncertainties (Li and Pye, 2018). However, a number of challenges were noted around the complexity of energy system modelling, translating qualitative inputs into quantitative parameters and the transparency of this transformation (Fortes et al., 2015), (Schinko et al., 2019), (Madlener et al., 2007), (Schmid et al., 2017), (McKenna et al., 2018), (Olabisi et al., 2010), (Zivkovic et al., 2016), (McDowall, 2012), (Sharma et al., 2020), (Ernst et al., 2018). Quantitative scenarios are inherently different from their qualitative counterparts as there can be no contradictions or inconsistencies (Schmid et al., 2017). In addition, a number of studies have highlighted fundamental limitations in quantitative modelling techniques, which cannot represent complex and dynamic systems like the energy transition as societal features (such as governance, institutional changes or energy-related behaviour) cannot be adequately described by numbers (Ernst et al., 2018), (Li et al., 2015), (McDowall and Geels, 2017). Furthermore, the translation process is subjective, depending on a researcher’s background and expertise, interpretations of qualitative narratives into quantitative parameters may differ (Robertson et al., 2017).

When dealing with scenario narratives combined with quantitative energy system models, researchers noted difficulties both with the translation of the narratives into parameters and communicating this to participants (Kowalski et al., 2009), (McKenna et al., 2018), (Olabisi et

al., 2010), (Zivkovic et al., 2016), (Eker et al., 2018), (Sharma et al., 2020). Firstly, the quantification of scenarios is done using assumptions based on the researcher's expertise. Secondly, taking the time to explain and justify these assumptions to participants will consume a significant portion of a workshop. However, if the modelling process is not clear then there is a risk that participants may be unsatisfied and thus dismissive of the outputs (Madlener et al., 2007), (Olabisi et al., 2010). As noted in Section 3.4 and 3.5, the present review suggests there is still work to be done in this area as it was found that in the majority of cases, the evaluation or assessment of modelling results was conducted by the research team. This was issue well summarized by (Simoes et al., 2019, p. 429), "*if stakeholders are engaged to provide feedback (which is not common practice), they are normally presented with a selection of more or less final results. Qualitative criteria are not used to assess them, and the modelling work is not subsequently corrected and redone*".

The challenge of making the modelling process more transparent was addressed in a couple of different ways. One study chose to give a significant portion of the workshop time to deciding with participants what the key drivers would be, thus making the model inputs as transparent as possible (Olabisi et al., 2010). Some other examples held a feedback workshop and allowed for revision / refinement of the modelling (Zivkovic et al., 2016), (Simoes et al., 2019), (Venturini et al., 2019). In the interest of having an interactive display that would enable participants to build their own scenarios and build an understanding of the different configurations a number of studies made use of the serious games approach, as discussed in Section 4.1.4.

3.6.2.2 Models do not represent reality

In line with the above challenge, a number of studies noted the difficulty of accurately representing the real-world with deterministic computer-based models (Fortes et al., 2015), (Schmid and Knopf, 2012), (Höltinger et al., 2016), (Venturini et al., 2019), (AlSabbagh et al., 2017), (Simoes et al., 2019). These tools have a number of intrinsic limitations such as failing to include consumer preferences, assuming perfect foresight and rational choice, not considering the amount of available capital for the purchase of new technologies (Simoes et al., 2019). As a result, the outputs and results may not match the expectations or everyday experience of participants (Fortes et al., 2015), (Schmid and Knopf, 2012), (Höltinger et al., 2016), (Venturini et al., 2019), (AlSabbagh et al., 2017), (Simoes et al., 2019). In addition, attempts to capture and quantify the 'social acceptability' of energy technologies risk

oversimplifying the complex variety of contextual factors that influence people's opinion (Höltinger et al., 2016), (Ernst et al., 2018). The diffusion of technologies will not play out as determined through least-cost optimisations, as there are a complex variety of non-monetary factors that have a strong effect on the individual decision-making of citizens (Li, 2017).

In one interesting example, technologies that stakeholders thought wouldn't play a part in their energy future were determined to be deployed after 2040, whereas other technologies that stakeholders thought could be promising in the future were determined to remain too expensive (Kowalski et al., 2009). Other studies noted the inability of the energy system model derived to capture institutional aspects that will have a significant impact on the rate of adoption (Schmid and Knopf, 2012), (Ernst et al., 2018).

3.6.2.3 Time, availability, and flexibility

Participatory approaches are very resource and time intensive due to the necessarily interdisciplinary nature of the research team as well as the investment in an engagement process. Dealing with issues around time and availability as well as being respectful of stakeholder's interests requires researchers to be flexible in their approach. This is at odds with conventional research projects that have predefined timelines and goals.

A large number of studies noted having difficulty firstly in recruiting the relevant participants, and secondly keeping them interested or engaged with the process (Kowalski et al., 2009), (Venturini et al., 2019), (McKenna et al., 2018), (Giannouli et al., 2018), (Vaidya and Mayer, 2016), (Macmillan et al., 2016), (Foran et al., 2016), (Mathy et al., 2015). One study experiencing an issue with stakeholder dropout, highlighted the difficulty in compensating stakeholders for their time and effort (Kowalski et al., 2009). Another noted that from the 36 participants that had been involved in the initial stage of the research only 17 were able to attend the workshop held due to time conflicts (Vaidya and Mayer, 2016). Moreover, most studies rely on participants self-selecting, as they don't have the resources to ensure a comprehensive representation of all relevant stakeholders (McKenna et al., 2018). This issue brings into question the legitimacy of research outputs given the often small sample sizes of people involved or lack of representation from particular stakeholder groups (Venturini et al., 2019), (Foran et al., 2016), (Ernst et al., 2018). Furthermore, in order to reach consensus with a diverse group of stakeholders lengthy discussions are required (Olabisi et al., 2010). However, the time available is often insufficient due to research resource constraints and stakeholder availability (Höltinger et al., 2016), (Dubinsky et al., 2019), (McDowall and

Eames, 2007). Having a broad range of worldviews improves the representativeness of the participants but brings with it the challenge that consensus may not be reached, particularly when the interventions take place over a limited timeframe (Höltinger et al., 2016), (Schmid et al., 2017), (Mathy et al., 2015).

Most of the methods discussed in this review sought to reach consensus as part of workshop discussions to agree a particular set of energy system goals or pathways. However, this is perhaps misguided, as noted by (Stirling, 2008) (cited in (McDowall and Geels, 2017, p. 43)) “*there is a need for caution about how such processes are structured, and what claims are made arising from them*”. The pursuit of consensus, particularly over a limited timeframe, risks oversimplifying the complex societal dynamics at play and shutting out some of the voices in the room. This is highlighted by the example of (Sharma et al., 2020), who found an “*abundant*” number of ‘areas of disagreement’ among participants and limited number of ‘areas of agreement’.

3.6.3 Considerations for future research

3.6.3.1 Process democratisation

As noted in Section 5.2.3, the time that participants have available is limited and must be respected as they are often simply volunteering to help the research. However, the engagement process should be as iterative as possible in the interest of transparency, mutual learning, knowledge exchange and the credibility/robustness of the outputs (Norström et al., 2020). Simply asking participants their opinions or perspectives and not facilitating feedback or evaluation of the analysis is not a meaningful engagement. It is important that participants understand how their input contributed to the research and results (Uwasu et al., 2020). Otherwise, they may feel disheartened with the process and subsequently lose trust in research and participation more generally, often referred to as ‘research fatigue’ (Clark, 2008). In light of this, it is striking that 36% of the studies reviewed involved just a single interaction with the participants.

The value of an iterative process is clear. Interviewing the stakeholders individually before coming together to work in a series of group workshops is useful firstly for understanding the diversity of perspectives and secondly for tailoring the material to ensure workshops run smoothly. In an iterative process, a workshop setting then provides a space for revision of both the qualitative descriptions and quantitative analysis (Schmid and Knopf, 2012), (Venturini et al., 2019), (Busch, 2017), (Ernst et al., 2018). Allowing the participants to review the

integration of their inputs into the quantitative analysis can help to alleviate this major methodological challenge. In one interesting example, the results of a series of workshops were evaluated by a public survey of 418 residents from the city of interest (Uwasu et al., 2020). This allowed the outputs from a selected group to be assessed against the concerns and priorities of the wider public. In the subnational studies, it was noted that the iterative nature of the process is particularly beneficial in building a relationship with local stakeholders (Busch, 2017), (Salerno et al., 2010b).

On from an iterative consultation process, the pursuit of co-production and collaborative approaches is seen as the most meaningful way to engage stakeholders in the energy system modelling and planning process. However, only ten of fifty-nine studies (17%) reviewed noted some form of collaboration outside of the formal engagement process, with just eight involving a transdisciplinary committee. In one instance although no formal committee or team was formed to oversee the research, the researchers took the time during the first in a series of workshops to agree with the stakeholder group the rules of collaboration (Höltinger et al., 2016). This is a very important trust building exercise as it hands over some of the control to the participants. Jointly defining the research questions and process facilitates the formation of a working relationship, while also ensuring that the research is of relevance and use to the stakeholders involved (Schmid and Knopf, 2012), (Vargas et al., 2018), (Dubinsky et al., 2019), (Salerno et al., 2010b). This is of particular importance for subnational studies, where the ‘co-management’ of the research project by representatives from the community provides an opportunity for them to build capacity, which is vital to the legacy of a project (Vargas et al., 2018). It is essential to facilitate extensive dialogue with the relevant stakeholders in order to facilitate an adaptive and flexible management of the research project to stay in line with the objectives, which helps to ensure real-world impact and value.

A further consideration is the practical running of the engagements and representativeness of stakeholders involved. As outlined in Section 3.4, the vast majority of studies involved consultation with energy/environmental experts, failing to reach beyond an already interested and engaged group. In addition, in most cases it appeared that the studies had relied on their own researchers to fulfil the role of facilitators during these events. This is perhaps because funding for such research projects generally does not allow for external facilitators to be used. However, its importance was noted in a number of different ways. (Olabisi et al., 2010, p. 2703) note that “*We used a highly skilled and experienced facilitator....his involvement was a critical aspect of the project’s success, as indicated by workshop participant comments on post-*

workshop evaluation forms". While (Kowalski et al., 2009, p. 1069) note that being "*led by professional facilitators, ensured that all participating stakeholders had opportunities to speak and that minority views were also heard*".

3.6.3.2 Future research direction

There are a number of emerging research directions in this area, two of which stand out in the context of this review and offer exciting prospects for future research. Firstly, as has already been suggested in other reviews (Trutnevyte et al., 2019), in order to more accurately represent the interaction of technical, economic, societal and environmental factors new models and approaches are needed. This has prompted much debate on the topic of so-called socio-technical energy transition (STET) models (Köhler et al., 2019), and the prospect of modelling the dynamics of sustainability transitions as oppose to simple techno-economic representations of the energy system (Köhler et al., 2018). Out of this, a number of opportunities have been highlighted (Li et al., 2015). However, this comes with a trade-off. These efforts may provide a more accurate representation of the energy transition and societal dynamics at play leading to more diverse and interesting research but will increase model complexity, which could be counterproductive to the goal of process democratisation.

Secondly, as highlighted by (McDowall and Geels, 2017), there are a number of fundamental and operational challenges to explain why quantitative computer-based models cannot represent complex non-linear societal dynamics. Thus, perhaps the two should be addressed separately (Geels et al., 2016). This review has highlighted that there is still work to be done in opening up the energy system modelling and planning process, which calls for greater attention to be given to the participatory elements. The limited progress to date is perhaps reflective of the fact that climate funding to date has favoured the technical sciences and failed to provide adequate capacity in the social sciences (Overland and Sovacool, 2020). Further investigation into what collaborative and co-production approaches can offer is needed. This will require open and transparent models in line with growing trends within the modelling community (DeCarolis et al., 2020), as well as the use of creative ways of dialogue and deliberation. This will help to build trust and understanding, but it is not without its own challenges. There are a range of unresolved questions such as the tensions between real-world impact and research outputs, representativeness of stakeholder groups involved, evolving role of science in society and changing responsibilities of researchers.

3.6.3.3 Limitations of study

As with any systematic review process, a limitation and potential bias within the present study is the search terms used to identify literature for analysis. Although, as outlined in (McGookin et al., 2021d), a range of different terms were explored and 715 studies analysed, the keywords were chosen to cover a broad range of practices and analysis. This was done to establish an understanding of this new and emergent field. There may be scope for further investigation with the use of more specific keywords. For example, the different quantitative analysis identified in Section 3.5 like ‘agent-based modelling’ or ‘MCDA’ could have subsequently been used as search terms in place of ‘energy system modelling’ or as oppose to using the term ‘energy’, the sectors of ‘heating’, ‘transport’ and ‘electricity’ are also potential search terms.

For the propose of this review, the progress in process democratisation was the primary focus. However, there is perhaps also scope for review of how participatory approaches have increased the diversity of energy research outputs or to what extend it improves our representation and understanding of the energy transition.

3.7 Conclusion

This paper provides a comprehensive review of participatory methods combined with energy system modelling and planning. The review explores two differing spatial scales and motivations; national policy-focused and local action-orientated research. The primary focus was to build an understanding of the range of qualitative and quantitative methods available, as well as assessing progress to date in the democratisation of key energy system decision-making processes. As part of the review a conceptual framework has been developed to help understand what the integration of participatory methods in energy system modelling and planning entails. The compiled database of fifty-nine studies highlights the breadth of knowledge already available in this emergent field. However, one of the key findings from this review is that there is still work to be done in following the principles of collaborative/co-production approaches. Only ten of the studies reviewed noted some form of collaboration with non-academic stakeholders. In the vast majority of cases, the engagement process was solely a consultation to extract information and had not allowed participants to shape the research direction or discuss and provide feedback on the results. In addition, a number of other considerations for future research have also been discussed such as the prospects of modelling socio-technical transitions, difficulty in dealing with complexity, the transparency of the model building process and challenge of recruiting a representative participant group.

Chapter 4 An innovative approach for estimating energy demand and supply to inform local energy transitions

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Keywords: Local energy planning; Regional energy transitions; Rural peripheral regions; Sustainable energy action plans; Covenant of mayors; Transport energy demand

4.1 Abstract

A vital first step for regional energy transitions is to develop an understanding of the current energy balance and related carbon dioxide emissions. However, there is a lack of clarity within existing literature on how best to determine a complete regional energy balance including industry, residential, services, agriculture, and transport sectors. This paper identifies four key limitations in the literature: over-reliance on simple population-based proportioning, a narrow focus on building energy, subsequent omission of transport energy in the majority of studies and a lack of transparency in a significant number of studies. This paper proposes a novel conceptual framework to address these gaps using a combination of local energy usage indicators and national unit energy consumption statistics. The authors apply this multi-dimensional approach to a rural case study region, carefully examining the range of energy usage indicators in each sector before selecting the most suitable. The results quantitatively demonstrate the value of this approach, with the final energy demand in some sectors varying by as much as double or threefold compared with a population weighting. Focusing on the socio-economic drivers of energy demand in this manner provides useful insights into the local context that defines the energy system.

4.2 Introduction

The majority of energy system modelling techniques seek to inform strategies to meet emissions reduction targets at a national or multi-national level. However, there has been a growing call for local efforts addressing climate change. These sub-national efforts at climate change action fall under a variety of spatial scalings; regional, municipal and city or town (Droege, 2012). While key elements like infrastructure developments and institutional frameworks (such as building codes and planning laws) must be stepped up and managed at a national level, there is an increasing need for the involvement of local stakeholders, especially

local authorities, in the design and planning process (Sperling et al., 2011). This has been prompted by the ever-increasing levels of renewable generation shifting the balance of the energy system from the conventional centralised model towards one that is more decentralised. Supported by policy seeking to pilot / model exemplar areas in order to showcase and promote the energy transition process (Späth and Rohracher, 2012), along with changing governance and institutional structures in support of greater community involvement (Koirala et al., 2016).

There is a growing body of literature highlighting the importance of small-scale / local / regional action in addressing the complexity of the energy transition and transformation (Droege, 2012), (Mattes et al., 2015), (Selvakkumaran and Ahlgren, 2017). Sub-national efforts at climate change action fall under a variety of spatial scaling; regional, municipal and city or town. Brought about by the ever-increasing levels of renewable generation shifting the balance of the energy system from the conventional centralised model towards one that is more decentralised (Manfren et al., 2011). Supported by policy seeking to pilot / model exemplar areas to showcase and promote the energy transition process (Späth and Rohracher, 2012), along with changing governance and institutional structures in support of greater community involvement, transitioning them from passive consumers to active prosumers (Koirala et al., 2016). In the context of regime transformation, local energy transitions fulfil an important role by bridging the gap between early adopters and other actors as a testbed for new technologies, demonstrating the success of new ideas and thus overcoming the stigmas surrounding unproven or unfamiliar technologies (Broekhans, 2013).

Local energy transitions, situated in small regions mean that many relevant actors already know each other from frequent face-to-face interactions (Späth and Rohracher, 2010). Participants in a study examining two German case studies emphasised the importance of the informal, personal networks contribution to the evolution of the local energy transition (Mattes et al., 2015). Through these networks more effective lines of communication can be formed which facilitate the creation of a more transparent decision-making process. In doing so, opening a dialogue around siting / placement of technologies that allows concerns to be heard and bases the decision on less economically favourable solutions in the interest of social acceptance (Mundaca et al., 2018).

A prevalent characteristic of some of the exemplar regional energy transitions such as Güssing, Austria (Koch R, 2006), Samsø Island, Denmark and Feldheim, Germany (Mundaca et al., 2018) has been their rural and isolated nature. For these communities, suffering from economic

decline, the opportunity of new employment and a reduction in imported fossil fuels underpinned a strong unifying vision (Späth and Rohrer, 2010). It has been shown that in times of economic crisis, investments in sustainable energy is an effective means of driving job creation and industrial development (Lund and Hvelplund, 2012). Emanating from this is the concept of regional energy autarky or energy independence that seeks to replace imported fossil fuels with local renewable sources (Müller et al., 2011). This brings ecological, social and economic benefits, which are particularly important in peripheral, rural and declining regions.

The practice of municipal-level energy planning has existed within European countries such as Sweden (Nilsson and Mårtensson, 2003) and Denmark (Möller, 2012) for a number of decades. Thus, it was expected that there may be a number of useful examples for how to determine local energy demand and supply across multiple sectors. However, it was found that the means by which initial estimates of energy supply and demand can be determined lacks coverage in literature to date. From the studies reviewed, four clear trends emerged. An over-reliance on simple one-dimensional population-based proportioning, which fails to account for regional deviations such as the levels of industrial activity or access to public transport. A focus on urban building and in particular housing stock models, which is not suitable in rural areas. The omission of transport energy in the majority of studies, despite it likely being a significant source of energy demand. In 2017, transport accounted for 31% of the total energy demand within the EU28 (Eurostat, 2017). Finally, there was a lack of transparency in the majority of studies on how the energy balance had been determined, with most relying on external reports from the area. This missing information makes it difficult for the studies to be replicated and undermines the analysis carried out.

The paper is structured as follows. Section 4.3 provides an overview of literature on the topic. Then in Section 4.4 the chosen case study region is introduced. Section 4.5 gives an outline of the multi-dimensional approach proposed, including some examples of energy demand and supply calculations. The resultant estimates of energy demand, assessment of the different EUIs and energy supply are all discussed in Section 4.6. Finally, Section 4.7 reflects on the ways in which the approach could be improved and considerations for future work.

4.3 Literature review

This literature review focuses on studies examining subnational energy systems. The criteria for selection was that the study in some way analysed a regional energy system, allowing for the scale of the region to be any sub-national area (county/municipality or city/town).

A vital first step for these sub-national efforts is to develop an understanding of the current energy balance and related CO₂ emissions (Brandoni and Polonara, 2012a). This is highlighted by the requirement when joining the Covenant of Mayors to commit to the development of a Baseline Emission Inventory (BEI) as a pre-requisite for the creation of a Sustainable Energy Action Plan (SEAP) (European Commission, 2010a). While this requirement provides a good precedent, the supporting documentation fails to provide reasonable explanation or guidelines for the development of a regional energy balance (European Commission, 2010b). The approach outlined focuses on urban/city development and in particular building stock models. It relies on the gathering of data from energy suppliers and grid operators or through the distribution of a survey to determine the current energy balance.

The limitations of this are outlined in literature on the topic. (Coelho et al., 2018) reviewing Portuguese cities found that only 50% had submitted a SEAP and BEI with detailed data. They highlighted the challenge of data availability, which is even greater in isolated rural areas where there is a reliance on surveys of individual households and businesses. Surveys of this manner are unlikely to receive a significant response rate, and as a result will not deliver an accurate energy balance. For example, (Schmidt et al., 2012) received only a 1% response rate from business establishments when conducting a survey of energy demand and fuel consumption in an Austrian region. This emphasises, as noted by (Marinakis et al., 2017b, p. 3), following a review of SEAPs in rural regions that; *“there is the need for a methodology, appropriately customised to the rural communities”*. Rural communities are at a distinct disadvantage and thus require easy-to-use tools to support local energy planning (Doukas et al., 2012). While most sub-regional analyses focus on the future of cities and urban areas, 26% of the European population currently lives in rural areas. Although this share is expected to fall due to the increasing levels of urbanisation, recent projections indicate around 20% will still be living in rural areas by 2050 (United Nations, 2018).

As can be seen in Table 4-1 below, the majority of studies reviewed lacked transparency on how the energy balance had been determined. In a significant number of cases the current energy demand was taken from previous reports on the region. Some had access to data on building energy demand or the electricity system profile. Other studies derived the regional energy balance from state statistics but provided no explanation of how this had been done. In another example, a comprehensive list of EUIs and references is given but no explanation is provided of how these were used to determine the energy demand of the municipalities examined (Weinand et al., 2019a). Some examples from Denmark looking at only heat demand

made use of GIS-based ‘heat atlases’ to map out building heat demand and identify supply options, with a particular focus on district heating (Möller and Nielsen, 2014). (Sperling and Möller, 2012) assess the district heating potential of an urban building stock, while (Petrović and Karlsson, 2016) investigate the potential of the residential building stock for an entire region.

Table 4-1. Sources of initial energy demand estimate in studies reviewed

Study	Source of initial energy demand estimate
INSMART–Insights on integrated modelling of EU cities energy system transition (Simoes et al., 2018)	sustainable energy action plan
Investigating long-term energy and CO2 mitigation options at city scale: A technical analysis for the city of Bologna (Assoumou et al., 2015)	
Modelling the energy system of Pécs – The first step towards a sustainable city (Kiss, 2015)	
A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass (Alberg Østergaard et al., 2010)	strategic energy plan
Planning regional energy system with consideration of energy transition and cleaner production under multiple uncertainties: A case study of Hebei province, China (Gong et al., 2020)	
Regional level approach for increasing energy efficiency (Alberg Østergaard et al., 2010)	
Energy systems modelling to support key strategic decisions in energy and climate change at regional scale (Di Leo et al., 2015)	regional energy environmental plan
The role of decentralized generation and storage technologies in future energy systems planning for a rural agglomeration in Switzerland (Yazdanie et al., 2016)	previous municipal report

Cost optimal urban energy systems planning in the context of national energy policies: A case study for the city of Basel (Yazdanie et al., 2017)	national / local statistics with no explanation of methodology
Energy supply modelling of a low-CO2 emitting energy system: Case study of a Danish municipality (Sveinbjörnsson et al., 2017)	
An integrative analysis of energy transitions in energy regions: A case study of ökoEnergierland in Austria (Hecher et al., 2016)	
Assessing energy performances: A step toward energy efficiency at the municipal level (Poggi et al., 2017)	
Energy modelling towards low carbon development of Beijing in 2030 (Zhao et al., 2017)	
Transitioning Island Energy Systems—Local Conditions, Development Phases, and Renewable Energy Integration (Marczinkowski et al., 2019)	data available
The role of municipal energy planning in the regional energy-planning process (Brandoni and Polonara, 2012a)	
Municipal scale scenario: Analysis of an Italian seaside town with MarkAL-TIMES (Comodi et al., 2012a)	
Balanced renewable energy scenarios: a method for making spatial decisions despite insufficient data, illustrated by a case study of the Vorderland-Feldkirch Region, Vorarlberg, Austria (Nabielek et al., 2018)	
Local authorities in the context of energy and climate policy (Comodi et al., 2012b)	

A summary of the methods found during the review can be seen in Table 4-2 & Table 4-3, listed from most recent to oldest publication date. The approaches used for estimating the energy demand by sector can be categorized as either top-down or bottom-up. A top-down (or downscaling) approach uses statistical indicators to estimate the proportion an area is

responsible for out of the national energy balance, while bottom-up builds an aggregated model based on an energy usage profile of buildings or vehicles within the area. Only four studies were found to detail a top-down approach for the whole energy system with the five sectors taken for this study. In the other top-down approaches one study omits transport, another two omitted agriculture and one omitted both agriculture and transport. Others focused solely on the building stock using a bottom-up approach at a city level include a variety of different scales, with some just covering residential while others include residential, services and industrial buildings. In cases where a top-down proportioning approach was used only the relevant statistic is highlighted, while greater explanation is provided for the bottom-up approaches in order to accurately present the variation across studies.

Table 4-2. Summary of top-down methods for developing a regional energy balance from literature reviewed.

Ref.	Agri / Fishing	Industry	Residential	Services	Transport
(Weinand et al., 2020a)	NA	Weighted matrix from area, population, number of companies, employees, and salaries	Weighted matrix from area and population	Weighted matrix from population and employee salaries	NA
(Ahn et al., 2019)	NA	gross domestic profit	population	population	number of vehicles per category _a
(De Luca et al., 2018)	utilized agricultural land area	employees	population	number of active units	number of vehicles per category _a
(Lind and Espegren, 2017)	NA	population	NA	population	vehicle km
(Jenssen et al., 2014)	utilized agricultural land area	employees	number / size of households	employees	population , private car only
(Waenn et al., 2014)	population	population	population	population	population , private car only
(Schmidt et al., 2012)	employees	employees	NA	employees	NA

(Brandoni and Polonara, 2012b)	NA	NA	NA	population	NA
(Curtin, 2011)	utilized agricultural land area	fuel spending	number of households / oil boilers	proportioned fuels based on national ratio to electricity consumption _a	number of vehicles per category _a

Note A – Those that state number of vehicles considered both cars and freight, otherwise when stated just cars the study only considered private car travel. All studies only accounted for fuel supplied in the region so neglected other transport demands such as aviation, fuel tourism and rail.

Note B – NA; Not Applicable as it was omitted from the study

Table 4-3. Summary of bottom-up methods for developing a regional energy balance from literature reviewed.

Ref.	Sectors	Method
(Garriga et al., 2020)	Residential	3 regional specific building archetypes used
(D'Alonzo et al., 2020)	Residential	dwellings by type and age aggregated based on average demands and floor area
(Weinand et al., 2019b)	Services, Residential and Industry	database of building typologies used to simulate energy demand data
(Oregi et al., 2018)	Services, Residential and Industry	energy performance variables (i.e. building age, building use, floor area, height / number of floors and volume) used in combination with heating and cooling degree hours
(Hukkalainen et al., 2017)	Residential	dwellings by type and age aggregated based on average demands and floor area
(Lind and Espegren, 2017)	Residential	number of people and floor area per dwelling, as well as energy service demand (kWh/m ²)

(Kohler et al., 2016)	Residential	energy performance variables (i.e. building age, housing types, floor area and inhabitant density, type of the heating system and fuels) applied to housing stock
(Orehounig et al., 2014)	Services, Residential and Industry	buildings grouped by purpose and construction period then floor area, U-values, and assumed air change rates used for simulation of hourly energy demand
(Schmidt et al., 2012)	Residential	estimated with a heat demand model based on the size and age of buildings
(Brandoni and Polonara, 2012b)	Residential	dwellings by type and age aggregated based on average demands and floor area
(Domac et al., 2011)	Residential	thermal energy based on the age of the building, heating area, isolation, and standard of living

The lack of consistency across the literature highlights the absence of a standard methodology for estimating sectoral energy demand at a regional level. It may also demonstrate how different approaches are suitable for different scales and regions: for example, municipal regions versus rural agricultural ones. One of the reasons for this variation may be the limited amount of data available and differing datasets available in different countries / regions. Something that became apparent was the different levels of data reporting and recording present. In addition, the approach will vary based on the purpose of the analysis. The majority of studies that involved building stock models did so because they were focused on heat energy demand, while others covering all (or most) sectors looked at all or multiple elements of the energy system.

4.4 Case study

As noted previously in Section 4.2, some exemplar regional energy transitions have been isolated rural areas. This is quite apparent from two prominent exemplars of regional energy transitions; Güssing, Austria (Koch R, 2006) and Samsø Island, Denmark (Mundaca et al., 2018). In Ireland, similar challenges can be seen throughout rural areas within the Border, Midlands and Western regions. One particularly interesting region is the Dingle peninsula, a small isolated 583 km² peninsula about 50 kilometres long and 15 kilometres wide, with a population of 12,500 (Central Statistics Office, 2016b), located in County Kerry (dotted line),

Ireland. Due to the absence of a gas grid and its highly dispersed population, the region spends a significant amount on the import of oil and electricity as in the cases of Güssing and Samsø.



Figure 4-1. Map of Ireland highlighting areas of interest; Co. Kerry (broken line) & Dingle peninsula (shaded)

Despite or perhaps because of its isolation, the Dingle peninsula has established itself as an extremely popular tourist destination (Lonely Planet, 2020), estimated to host roughly a million visitors each year (Failte Ireland, 2016). While this is a significant source of income for the area, it brings with it some challenges. The Dingle peninsula housing stock contains a significant amount of holiday homes at 25% of dwellings compared to 11% in Co. Kerry and 3.2% nationally (Central Statistics Office, 2016b). In addition, the limited employment opportunities outside of the hospitality sector and an increasing number of tourists makes the

area less attractive for young families to settle there. This is reflected in population / demographic statistics, with 41.1% of the population over 50 (Central Statistics Office, 2016b) compared to 30.4% across the state (Central Statistics Office, 2016c).

In the context of the energy transition, the Dingle peninsula presents a particular challenge. The highly dispersed nature of the households limits the options available for heating and transport. Existing initiatives in the area see electrification forming a large part of the solution (ESB Networks, 2018). However, the area currently relies on a single electricity 110kV line, which already struggles to maintain a reliable supply of electricity and will experience increased difficulty as heating and transport are electrified.

The selection of the Dingle peninsula as the case study for this investigation is based on its similarity to the examples of regional energy transitions outlined; firstly given the socio-economic context and secondly, the current dependence on imported energy and significant challenges decarbonisation poses. In addition, the choice of an isolated rural area highlights the issues around data availability and necessitates the study of transport energy demand, which was seen to be generally neglected in the literature.

In obtaining data for the Dingle peninsula, it was found that the majority of relevant statistics were only available at a county level, so Co. Kerry's energy balance was also determined. This usefully demonstrates the scalability and replicability of the approach derived. For the purpose of demonstration, this paper applies the approach to a small isolated rural area within Ireland, but it has applicability for any scale region. In the following sections, the Dingle peninsula will predominantly be referred to simply as Dingle, while when referring to the small town within the region, Dingle town shall be used. Likewise, County Kerry will be referred to simply as Kerry.

4.5 Multi-dimensional approach

This section will outline the multi-dimensional approach that was developed through this study. A key issue that emerged from the literature review (Section 4.3) was that while a range of top-down and bottom-up approaches already exist there is a lack of clarity and transparency in existing literature with no clearly defined best practice for how to estimate a subnational energy balance. The conceptual framework and approach proposed seeks to address this by offering a means to standardize the practice of subnational energy planners. It involves five key elements.

1. Data collection

2. Engagement with local and national stakeholders
3. Determining energy demand
4. Assessment of the representativeness and quality of the socio-economic indicators available and careful selection of method for each sector
5. Determining energy supply and associated CO₂ emissions

The novelty of this approach is as follows; clearly outlining the selection of method and EUIs with a range of options being explored in each sector, building a detailed understanding of the local context and determining a complete energy balance covering agriculture, industry, residential, services and transport sectors.

4.5.1 Data collection

A range of EUIs were gathered, those that had been identified in the literature review (Section 4.3), as well as some others found to be available such as the unladen weight of fishing boats or tonne km of freight vehicles. The granularity of data available was an issue throughout the calculations. Some are only available at the NUTS 3 (Nomenclature of Territorial Units for Statistics third level, developed by the European Commission) defined region of the Irish South West (including both County Kerry and Cork), while others are only available at a county level. The data collection and preparation process is outlined in detail within the accompanying Data in Brief (McGookin et al., 2021a).

4.5.2 Engagement with key local and national stakeholders

Throughout the data collection and analysis researchers engaged extensively with key stakeholders. Firstly, national and local organisations were contacted in efforts to improve the quality of the data, meetings were held with the Central Statistics Office and Kerry County Council. Secondly, in line with the review of academic literature on the topic, existing studies in Ireland were investigated and meetings held with experts in the field to discuss the approaches taken and data that was available. Finally, the analysis has been a collaborative effort with other members of the ‘*Corca Dhuibhne 2030*’ partnership established (MaREI Centre, 2022). Most notably the lead author sat on the Dingle Peninsula ‘Sustainable Energy Community’ steering group, which oversaw the development of an Energy Masterplan for the area informed by this analysis. This not only ensured the research was of value to the case study community but also provided a useful opportunity for researchers to gain a better understanding of the socio-economic context of the area.

4.5.3 Determining the energy demand in each sector

As stated above in Section 4.3, approaches for estimating the energy demand by sector can be categorized as either top-down or bottom-up. Firstly, a bottom-up approach involves building an aggregate model of energy demand based on energy benchmarks such as energy per metre squared of different building types and local statistics such as the total floor area of a building type. For example:

$$\text{energy benchmark} \cdot \text{regional statistics} = \text{regional energy demand} \quad (1)$$

$$\text{average kWh} / \text{m}^2 \cdot \text{average m}^2 \cdot \text{No. of houses}_{(\text{per age group})} = \text{residential energy demand} \quad (2)$$

Secondly, in the absence of the data necessary for a bottom-up approach, a top-down approach may be used. This involves proportioning (or downscaling) national energy data based on local statistics. It is based on the assumption that the energy demand will correspond to socio-economic drivers (Weinand et al., 2020a). For example:

$$\text{regional share} \cdot \text{national energy demand} = \text{regional energy demand} \quad (3)$$

$$\frac{\text{regional indicator}}{\text{national indicator}} \cdot \text{national energy demand} = \text{regional energy demand} \quad (4)$$

$$\% \text{ share of population} \cdot \text{national energy demand} = \text{regional energy demand} \quad (5)$$

Eq. (6) was re-arranged as follows;

$$\text{national unit energy consumption} \cdot \text{regional energy usage indicator} = \text{regional energy demand} \quad (6)$$

$$\frac{\text{national energy demand}}{\text{national statistic}} \cdot \text{regional statistic} = \text{regional energy demand} \quad (7)$$

$$\text{MWh} / \text{capita} \cdot \text{population of the region} = \text{regional energy demand} \quad (8)$$

By re-arranging the equation in this manner the national unit energy consumption (UEC) values and local energy usage indicators (EUIs) can be displayed. This enables the repetition of the approach in another region within the same country simply by gathering the relevant local statistics, which would help to greatly reduce the workload in preparing a regional energy balance. Similar to the work of Weinand et al., a database could be developed for the country that would generate a regional energy balance for any given subnational area (Weinand et al., 2019c). For repetition in a different country, the national unit energy consumption figures would have to be determined based on the relevant statistics to get the most accurate results. A

further benefit of this would be the ability to compare and contrast these energy indicators across regions and countries, as suggested by (Doukas et al., 2012).

4.5.3.1 Top-down approach calculation

For the majority of calculations, excluding the residential sector where a bottom-up approach (as discussed below in Section 4.5.3.2) was taken, the energy demand in each sector was determined using a top-down approach. The following examples will cover how this was carried out. Although a range of different indicators were used (as outlined in Table 4-2) the calculation follows two possible paths. Firstly, in cases where the data was available at the local level, the calculation is quite simple, for example using the number of employees in industry.

$$\text{National UEC} = \frac{\text{industry energy demand}}{\text{number of employees in industry}} \quad (9)$$

$$\text{National UEC} = 28,435.4 \text{ GWh} / 210,059 = 135.4 \text{ MWh /employee} \quad (10)$$

$$\text{Energy demand in region} = \text{national UEC} \cdot \text{number of employees in the region} \quad (11)$$

$$\text{Energy demand in Kerry} = 29.494 \cdot 5,695 = 770.9 \text{ GWh} \quad (12)$$

$$\text{Energy demand in Dingle} = 29.494 \cdot 433 = 58.6 \text{ GWh} \quad (13)$$

For other indicators that first had to be estimated before the energy demand calculation could be performed, the method was as per the following example using gross value added for industry:

$$\text{National UEC} = \frac{\text{industry energy demand}}{\text{gross value added of the sector}} \quad (14)$$

$$\text{National UEC} = 28,435.4 \text{ GWh} / \text{€}94,455 \text{ million} = 301.1 \text{ MWh /€ million} \quad (15)$$

$$\text{Energy demand in region} = \text{national UEC} \cdot \text{gross value added in the region} \quad (16)$$

$$\text{Kerry industrial energy demand} = 301.1 \cdot 1468 = 441.8 \text{ GWh} \quad (17)$$

$$\text{Dingle GVA 2016} = \text{Kerry GVA 2016} \cdot \% \text{ share of employees} \quad (18)$$

$$\text{Dingle GVA 2016} = 1,468 \cdot (433 / 5695) = \text{€}111.6 \text{ million} \quad (19)$$

$$\text{Dingle industrial energy demand} = 301.1 \cdot 111.6 = 33.6 \text{ GWh} \quad (20)$$

For Services and Industry in Dingle, the proportion of Kerry's employees was used to determine estimates for GVA and number of buildings, while in agriculture the hectares of

farmland was used to get the share of the GVA. The tonne km in road freight was determined for Kerry based on the share of km travelled in the South West region originating there. For transport in Dingle, public service vehicles were proportioned based on the number of employees, while tonne km and km travelled in road freight was based on the share of GVA estimated.

4.5.3.2 Bottom-up approach calculation

The residential sector was the only case with the data needed to take a bottom-up approach. Combining the age profile of the housing stock in the region of interest (which was available at the Small Area) with known values for the energy demand and average floor area by household age can provide an estimate of energy demand as follows.

$$\text{Energy demand} = \text{No. of dwellings in age category} \times \text{Avg. } m^2 \times \text{Avg. kWh} / m^2 \quad (21)$$

An issue that emerged, as is documented in literature on the topic (Mac Uidhir et al., 2020), was the fact that the energy rating doesn't reflect actual energy demand. Using the Irish Building Energy Rating (BER) database to determine the values for energy demand per metre squared will likely produce an overestimate. This was confirmed by applying the values to the national housing stock and comparing to the reported figures, which was found to have been overestimated by 57%. It was addressed by deriving a simple correction factor as follows.

$$\text{Correction factor} = \frac{\text{estimated energy residential demand}}{\text{reported residential energy demand}} \quad (22)$$

$$\text{Correction factor} = \frac{31,448}{49,245} = 0.6386 \quad (23)$$

Given the limited data on the housing stock in the case study region, this was deemed sufficient. However, for future analysis a more detailed housing stock model could be developed using different correction factors for each energy rating category as developed in (Mac Uidhir et al., 2020).

4.5.4 Assessment of socio-economic energy usage indicators

In order to decide the most appropriate EUI in each sector, a representativeness and quality index was developed. For representativeness, this looked at the ability of the EUI to account for the size, level of activity and type of activity in the region. The quality was based on the granularity of the data available and if it came from the relevant year (2016). The selection of EUIs is discussed in Section 4.6.1.

4.5.5 Determining energy supply and associated CO₂ emissions

As with the determining of energy demand, there is little data available on energy supply below national level. At a county level industry and service sectors are grouped as non-residential buildings. To address this issue, the national share for the sector was adjusted based on changes in the overall heating system fuel share. There is no natural gas grid in Co. Kerry, and according to the Non-Domestic BER database shown below, it was replaced as follows.

Table 4-4. Primary heating fuel in non-domestic buildings Ireland and Kerry 2016 (Central Statistics Office, 2016e)

	Ireland	Kerry	Difference
Gas	25%	0%	-25%
Oil	10%	24%	14%
Electricity	62%	69%	7%
LPG	2%	6%	4%
Solid Fuel	1%	1%	0%

$$\text{Share of gas use replaced in heating} = \text{increase in fuel use} / \text{national share of gas} \quad (24)$$

$$\text{Share of gas use covered by Oil} = (14 + 4) / 25 = 72\% \quad (25)$$

$$\text{Share of gas use covered by Electricity} = 7 / 25 = 28\% \quad (26)$$

$$\text{Adjusted fuel share of total energy demand} = \text{original fuel share} + \text{share of gas use replaced} \quad (27)$$

$$\text{Adjusted Oil value} = 20\% + (0.72 \times 32.9\%) = 43.7\% \quad (28)$$

$$\text{Adjusted Electricity value} = 35.3\% + (0.28 \times 32.9\%) = 44.5\% \quad (29)$$

The associated CO₂ emissions are then determined by applying national conversion factors (Sustainable Energy Authority of Ireland, 2021a).

4.6 Results

This section outlines the resultant energy demand per sector (agriculture and fishing, industry, residential, services and transport) in the case study region. Firstly, the selection of the most appropriate indicators using an index for representativeness and quality is detailed in section 4.6.1. Then in Section 4.6.2, the range of energy demand values in each sector is provided in

Figure 4-2, as well as the final chosen values based on the findings of Section 4.6.1, which are shown in Table 4-5 and Figure 4-3.

4.6.1 Analysis and choice of the energy usage indicators

During the literature review, the reasons for selecting commonly used indicators did not become apparent. It was found that in the vast majority of studies no explanation was given for why the chosen indicators had been used, other than it was the data available. To address this issue, an index was devised to objectively assess the representativeness and quality of the indicators, as displayed in Table 4-5. Each indicator was rated out of a total of 8 points, which were allocated as follows.

Representativeness (1 point each)

- Asserted in literature – it was noted as a commonly used indicator in the literature reviewed
- Size of sector – it can give an indicative gauge of the share of that sector contained within the region of interest
- Level of activity – differing to size as a measure of how much activity takes place in the region of interest. For example, the number of enterprises can tell you the level of activity but gives no indication of how large the buildings are.
- Type of activity – can account for the different types of activity within a sector, i.e. different farming outputs, more energy intensive industry, freight carrying bigger loads.

Quality

- Spatial quality – determined by the granularity of the data, if it was available for the area of interest by aggregating the relevant Small Areas it got 2 points, whereas those only available for County Kerry got 1 point
- Correct year (1 point)
- Accuracy (1 point) – a measure of confidence in the data. This was primarily an issue with employee statistics. As the data comes from a Census survey, it will reflect the occupancy of people living in the area but may not be the number of actual employees located there if people commute outside of the area for work.

Table 4-5. Index to assess the representativeness and quality of the energy usage indicators.

Sector	Indicator	Representativeness					Quality				Total (0 - 8)	
		In lit.	Size	Level of activity	Type of activity	(0 - 4)	Spatial quality		Data quality			(0 - 4)
							Small Area	County	Year	Accuracy		
							1	1	1	1		
All	Population			1		1	2		1	1	4	5
Agriculture & Fishing	Employees		1	1			2		1		3	5
Agriculture	Gross value added		1	1	1			1	1	1	3	6
Agriculture	Area of land	1	1	1			2			1	3	6
Fishing	Gross value added		1	1			2		1	1	4	6
Fishing	Unladen weight of boats		1	1	1			1		1	2	5
Industry	Enterprises			1				1	1	1	2	3
Industry	Employees		1	1			2		1		3	5
Industry	Gross value added	1	1	1	1			1	1		2	6
Commercial Services	Enterprises			1				1	1	1	3	4
Commercial Services	Employees	1	1	1			2		1		3	6
Commercial Services	Gross value added		1	1	1				1	1	2	5
Public Services	Enterprises			1				1	1	1	3	4
Public Services	Employees	1	1	1			2		1		3	5

Public Services		Gross value added	1	1	1	3		1	1	2	5
Residential		Houses	1	1		2	2	1	1	4	6
Transport freight	-	Road Vehicles	1	1		2		1	1	3	5
Transport freight	-	Road Distance travelled	1	1		2		1	1	3	5
Transport freight	-	Road Weight carried	1	1	1	3		1	1	2	5
Transport - Private car		Vehicles	1			1	2	1	1	4	5
Transport - Private car		Distance travelled	1	1		2		1	1	3	5

As a further assessment of representativeness, a regression analysis was attempted looking at the relationship between the national recorded energy data and EUIs over a 10-year period (2008 to 2018). However, there was insufficient data on a number of the EUIs to draw any meaningful conclusions from this. For example, population figures and the employees in agriculture/fishing come from the Census of Ireland and thus are only available at 5-year intervals, while the GVA is only available from 2014 – 2018.

Based on the assessment index in Table 4-5 and some additional assertions, the choice of EUI is outlined below. The index provided useful quantitative figures for comparison, but it should be noted that it doesn't guarantee with absolute certainty the respective representativeness of each EUI. In addition, it's not clear if representativeness should be favoured over data quality, if the two are equally important, or vice versa.

- Agriculture – Hectare of farmland was the mostly commonly used EUI in the literature and scored the same as GVA in the assessment index. However, GVA was chosen as it may better capture the fact that Kerry has less arable land and dairy farming, the highest earning and most energy intensive.
- Fishing – Although scoring lower on quality, gross boat tonnage was chosen over GVA for its representativeness as there will be a clear link between the size of the boats and their fuel consumption.
- Industry – GVA was chosen as it scored highest in this sector and is frequently used as a means of classifying industrial energy intensity (Silveria and Luken, 2008), although only one of the studies reviewed made use of it.
- Commercial Services – GVA was chosen over employment figures. Although employment figures were available for Dingle from the 2016 census (Central Statistics Office, 2016a), an issue within this sector is that large portion of it will be the hospitality sector, which is very seasonal with significant fluctuations in employees over the year. Thus, GVA was favoured as an indicator of the level of activity over the whole year.
- Public Services – As the impact of seasonality on employment would not be an issue for the public services, it was chosen over GVA, given it was the most popular indicator in the literature reviewed.
- Road freight – Tonne km scored higher on representativeness but lower on quality compared to the distance travelled as it was only available at regional level. However, was still chosen as a good measure of the activity in the sector.

- Private car – Distance travelled although scoring the same as the number of vehicles because the average km per car per year is only available at a county level, was still considered the best choice of indicator.

4.6.2 Energy demand per sector and resultant energy balance

The range of energy demand estimates in each sector is shown in Figure 2. In the majority of sectors, the estimates varied quite significantly, except residential where the difference was minimal.

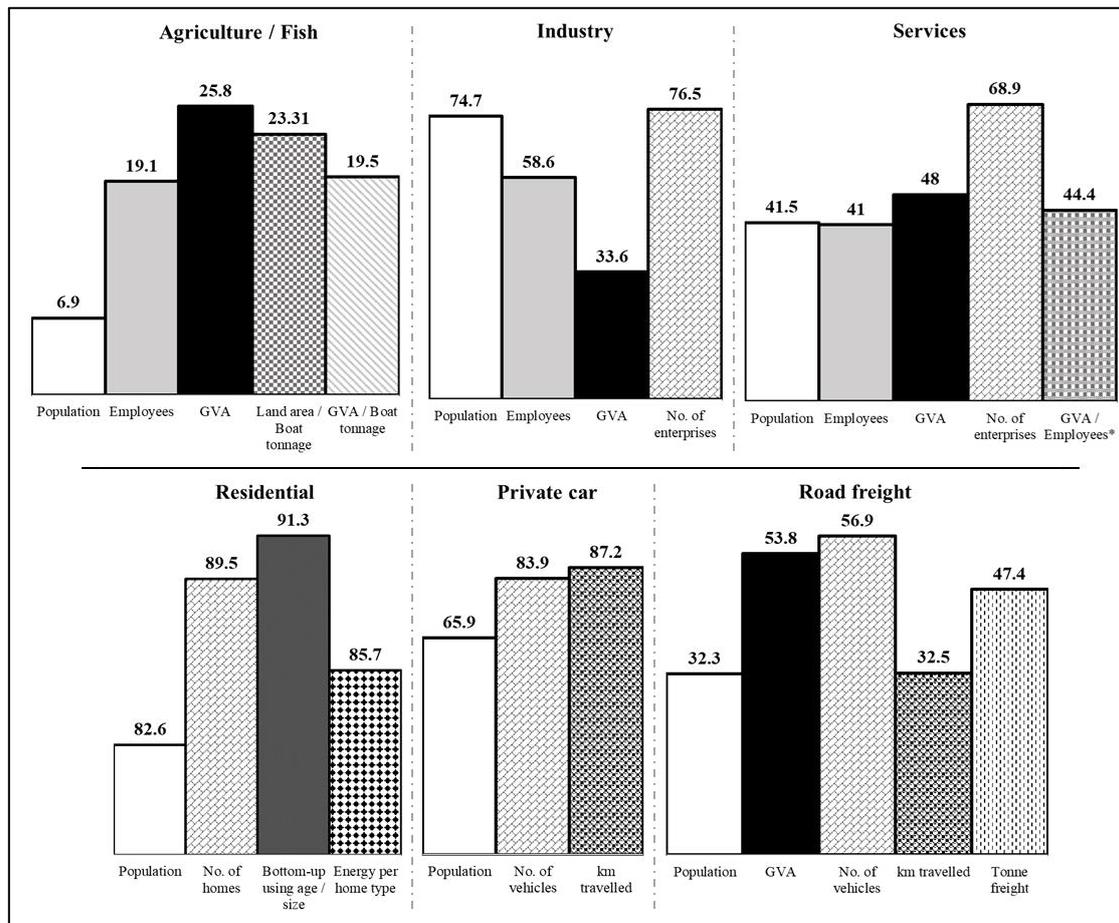


Figure 4-2. Range of energy demand estimates by sector and indicator used. *GVA for commercial services/employees in public services.

The energy demand figures based on the selected EUIs can be seen in Table 4-6. Using a population weighting can provide an indicative gauge of energy demand in a given region, but it is overly simplistic in that it assumes all regions within a country are the same. Without examining local socio-economic statistics, it fails to address deviations across regions such as the level of industrial activity, population density, public transportation infrastructure, age of the housing stock or levels of dependence on private cars. For example, in comparing the

energy demand shares by sector shown in Figure 3, it is clear that the level of activity in Transport and Agriculture/Fisheries sectors is significantly above the national average, whereas there is very little industrial activity.

Table 4-6. Comparison of population weighted and sector weighted estimates for Co. Kerry and Dingle energy balances in 2016.

	Kerry			Dingle Peninsula		
	GWh		% change	GWh		% change
	population weighted	sector estimates		population weighted	sector estimates	
Agriculture / Fisheries	81.5	135.9	67%	6.9	21.7	215%
Industry	882	441.8	-50%	74.7	30.1	-60%
Residential	975.5	991.3	2%	82.6	91.3	11%
Services	489.5	349.3	-30%	41.5	44.4	7%
Transport	1,342	1,436	7%	113.6	150.3	32%
Total	3,771	3,348	-11%	319	340	6%

The overall balance is displayed in Figure 4-3, comparing the differences between Ireland, Kerry and the Dingle Peninsula. In the context of the low carbon transition, Dingle’s geographical location as an isolated and sparsely populated rural peninsula poses a significant challenge. Kerry is Ireland’s fourth least densely populated county at 30.7 people/km², while the Dingle peninsula is even lower at 21.5 people/km². This is significantly lower than the EU NUTS 3 region average of 117.5 people/km² (European Commission, 2016). As a direct consequence of this, the two key sectors that dominate the energy balance are private car travel (accounting for 25%) and residential heating (accounting for 21%). Given to the rural nature of the area, car ownership on the Dingle peninsula is significantly above the national average at 547 cars / 1,000 inhabitants (Central Statistics Office, 2016b) compared to 428 cars / 1,000 inhabitants (Central Statistics Office, 2016c), an increase of almost 28%. Likewise, it is above the EU average of 505 cars / 1,000 inhabitants (Eurostat, 2016). Heating also presents a challenge, the area is currently heavily reliant on the import of oil with LPG (liquid petroleum gas) and kerosene boilers representing 71% of central heating systems compared to 41% nationally.

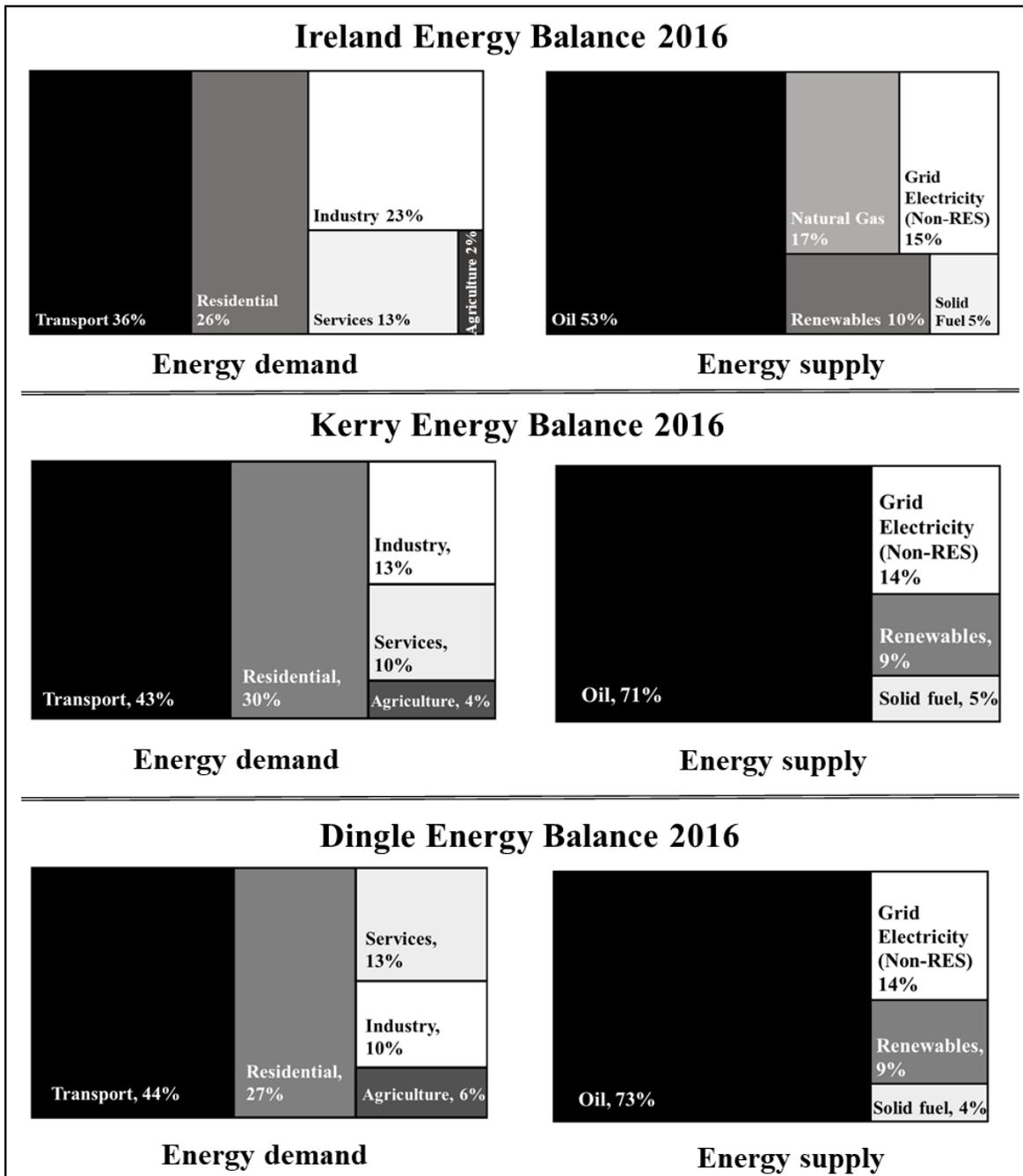


Figure 4-3. Energy balance in Ireland, Co. Kerry and Dingle in 2016.

4.7 Discussion

The comparison between population weighted and chosen sector estimates (Table 4-6) shows significant deviations at a sectoral level. Although the total energy demand values are relatively similar, the results in some sectors differ by as much as 60% or 215%. Without access to any recorded energy demand it is not possible to verify the accuracy of these results. However, they still highlight the value of examining the sectors individually and how this multi-dimensional approach can give greater consideration to local deviations and drivers of energy demand. The

population weighted estimate can be seen to represent the national average, which clearly does not represent the activity in the case study region.

There is scope for refining and improving this approach with better access to both local energy usage indicators and recorded energy data. Firstly, recorded energy data could be used to verify the results, and thus more accurately determine the most appropriate EUI in each sector. Without any recorded energy data, it is not possible to properly assess the representativeness of the various EUIs or impact quality has on the results. However, this approach has demonstrated, that the deviation from the actual values could be very large in some cases. Therefore, this needs to be further investigated in future studies. In addition, the rating of the various assessment criteria in the index developed during the selection process outlined in Section 4.6.1 could also be improved. At present, without a means of validation it is assumed that all the criteria are of equal importance. Secondly, with access to more comprehensive and granular data on key drivers of energy demand such as: the profile of the building stock or vehicle fleet characteristics bottom-up energy demand estimates could be determined. Another important addition would be increased temporal resolution. For example, in order to assess the impact of technologies like heat pumps and electric vehicles on the electricity grid daily load profiles would be needed.

As previously noted in Sections 4.4& 4.5, the approach developed in this paper may be applied to any scale region or area. However, in replicating this approach, the presented unit energy consumption figures should be revised based on the relevant country's national statistics. Not every region will have access to data on the EUIs chosen in this study or may indeed have access to other indicators that were not available in this case. It should be noted that there will likely be regional deviations in the representativeness of different indicators, and thus the choice of indicator might differ based on the region of study. Moreover, as suggested by Weinand et al., an interesting approach may be to look at the use of a weighted matrix with multiple indicators (Weinand et al., 2020b).

This paper has shown that taking a more thorough approach to develop a regional energy balance provides important insights that should be a prerequisite to any energy system analysis. It has illustrated how a valuable understanding of a region's socio-economic topography may be gained by gathering the relevant statistics used to determine the EUIs. The resultant understanding of potential local deviations from the national energy profile can serve to highlight key areas of concern to address. This can enable measures to be more appropriately

directed as part of national and local energy planning processes: examining energy demand reductions, efficiency improvements and renewable energy supply options. For example, in the case study region, it is clear that improving the energy efficiency of homes and exploring alternative transport options should be a priority. The transport sector, which was omitted from the majority of studies reviewed, accounts for 43% of the overall energy demand.

4.8 Conclusion

Across Europe, despite an increasing call for the development of local energy strategies, there is an absence of a standard methodology or guidelines for estimating a regional energy balance. Through the use of an isolated rural case study region this analysis has demonstrated the importance of developing an understanding of a local area's characteristics prior to conducting analysis on the energy system. Taking the time to carefully select the appropriate energy usage indicators and exploring the socio-economic profile of an area is an essential first step in the local energy planning process. However, one prominent issue that emerged throughout the analysis undertaken in this study was the lack of data available below national level, not just with regard to energy data but also socio-economic statistics. This highlights the value of having more decentralised governance in order to facilitate sub-national efforts at energy planning. Furthermore, in order to conduct well-informed energy system analysis, a degree of local knowledge is required, emphasizing the important role to be played by local authorities and other actors.

Chapter 5 Doing things differently: Bridging community concerns and energy system modelling with a transdisciplinary approach in rural Ireland

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Keywords: Transdisciplinary, energy system modelling, co-production, rural development, community wellbeing, participatory action research

5.1 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..

5.2 Introduction

Traditional approaches to energy planning, generally involve experts determining an ‘optimal’ solution from a technical perspective and then consulting with communities where the new infrastructure will be built or deployed (Heaslip and Fahy, 2018). In this *technocratic* approach, societal engagement is limited to an *add-on* or *box-ticking exercise*. (Knudsen et al., 2015) investigating local perceptions of procedural justice in four electricity transmission grid projects from Norway and the UK, found that across all cases the level of local involvement in planning decisions was insufficient and unjust. This can result in inevitable tensions emerging when communities feel excluded from key decisions in the planning process (Ceglarz et al., 2017), (Stadelmann-Steffen and Dermont, 2021). (Sillak et al., 2021) note that the recent and growing interest in collaborative approaches to energy planning has in a large part emanated as a response to the need to address weaknesses in the conventional technocratic approach. 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. This is an important factor, so important in fact that it can be understood as indispensable “*a conditio sine qua non*” for the acceptability of an engagement process. 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 (Revez et al., 2020).

Sustainability transitions are highly localised and place-dependent (Hansen and Coenen, 2015). As noted by (Colvin, 2020, p.11), 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*”. 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 (Trutnevyte and Stauffacher, 2012), (Meyer et al., 2019). The pressing local need to address issues such as demographic imbalance (with limited young families and growing share of aging population), population decline and limited economic opportunities calls for a broader understanding of a what sustainable future means across social, economic and environmental domains. What would be better described as a flourishing rather than merely sustaining current (unsustainable) practices of production, consumption and relationships with each other and the world around us (Ehrenfeld and Hoffman, 2013).

There is increasing debate on the prospects of modelling the broader social and political context within which energy systems operate. (Li et al., 2015) offer a critique of existing quantitative models due to the limited focus on technical feasibility and failure to address socio-political dynamics. 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 (Holtz et al., 2015). (McDowall and Geels, 2017) build on this, listing a number of fundamental and operational challenges to explain why quantitative computer-based models cannot represent complex transition dynamics. They suggest the pursuit of ‘plural and diverse’ approaches rather than efforts to simplify and integrate societal dynamics. Similarly, (Geels et al., 2016) 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). More recently (Trutnevyte et al., 2019) proposes that building new models or modifying existing models is needed in order to merge socio-technical theories and modelling approaches. While (Hirt et al., 2020, p. 175) 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.

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 seeking to work alongside non-academic stakeholders (Wittmayer and Schöpke, 2014), (Schneidewind and Augenstein, 2012), (Fazey et al., 2018), (Norström et al., 2020), (Caniglia et al., 2021). Co-production approaches have been recognised as offering an opportunity for researchers and non-academic partners to work together in achieving vital sustainability goals. Within energy research however, recent literature reviews have found a very limited number of existing examples of co-production approaches. (McGookin et al., 2021c) 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.

Likewise, (Galende-Sánchez and Sorman, 2021) 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. As (Solman et al., 2021) highlight in their review of co-production examples in wind energy projects, there is a need to go beyond the limited opportunity afforded by invited participations during solely the planning phase and open up the entire process.

There are nevertheless some useful examples of co-production approaches to energy system modelling and planning from which to draw on (McGookin et al., 2021c). 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 (Trutnevyte et al., 2011). (Schmid and Knopf, 2012) 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. (Zivkovic et al., 2016) likewise focus on a single sector, assessing heating scenarios for a Serbian city. (Heaslip and Fahy, 2018) take a more comprehensive view of the energy transition with an island case study, exploring topics like energy access, affordability, and security. However, also neglect the transport sector. (Dubinsky et al., 2019, p. 84) 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 in the region studied.

Drawing on previous suggestions for bridging rather than merging analytical approaches (Geels et al., 2016), (Trutnevyte et al., 2019), (Nilsson et al., 2020), (Hof et al., 2020), this chapter asks: *to what extent is it appropriate to seek 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 chapter develops two central scenarios, similar to the work of (Meyer et al., 2019), 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, that the public engagement carried out does not simply explore perceptions of climate change and consult on potential energy system alternatives. Rather it entailed a broader investigation into the opportunities for a desirable future incorporating social, economic, and environmental concerns. Stemming from this, an assessment of the societal capacity is performed, reflecting on the implications of twelve wellbeing indicators identified with regard the purposed energy scenarios. Finally, critical reflections are outlined on the co-production approach taken, what learnings it adds to the energy system modelling process and gaps in national policy identified by this small-scale energy system model.

5.3 Bridging participatory action research and energy system modelling

The following sections introduce the co-production approach taken, different ways in which the research consulted with the local community, the process for modelling future energy scenarios, and relationship between the two.

5.3.1 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 (Freire, 1982), (Wallerstein and Duran, 2008), (Scholz et al., 2006), (Kendon et al., 2007). However, transdisciplinarity as an emerging trend in sustainability science has appeared with a number of different interpretations (Scholz et al., 2006), (Mullally et al., 2017). 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” (Byrne et al., 2017) seeking new knowledge through participatory methods involving stakeholders from outside academia (Scholz et al., 2006). It is important however, as previously noted, to distinguish between extractive participatory methods (workshops, surveys, etc.) with limited dialogue or shared learnings and the pursuit of co-production approaches. Contemporary (un)sustainability challenges call for an approach to energy research that is action-orientated, focusing on solution processes and ‘how to’ practical knowledge in addition

to building further understanding of the problem (Fazey et al., 2018). As set out by (Norström et al., 2020), there are four key components to knowledge co-production.

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 (Späth and Rohrer, 2012), (Wittmayer et al., 2014).
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 (Lang et al., 2012), which allows for stakeholder input throughout the entire research process (see point 4 below).
3. It is *action-orientated*, 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 (Miller et al., 2014), (Polk, 2014).
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. It is particularly important that the community of interest be involved in the initial problem framing and design phase, in order to ensure the legitimacy and relevance of the work being carried out (Dubinsky et al., 2019), (Newig et al., 2019).

This paper is based on the experience of an ongoing collaboration between academic, national agencies (such as the national electricity distribution grid operator; ESB Networks) and local community representatives taking place on the Dingle Peninsula in Ireland's South West. The core research team consists of two PhD students from energy engineering and sociology, as well as an engaged research support officer (MaREI Centre, 2022). The area was identified as an opportunity to explore an 'engaged research' approach because of emerging complementary projects there (Mol Téic, 2020). The two central research strands involve analysis of the multi-stakeholder approach to the socio-technical transition (see (Boyle et al., 2021a)) 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 set out by Norström et al. (Norström et al., 2020).

1. The work has been conducted as part of an ongoing project "*Corca Dhuibhne 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 across social, economic and environmental domains.

2. The research team setup and coordinates a collaborative governance committee to oversee activities in the area and facilitate input into the research design and implementation process (Watson et al., 2020). This committee comprises seven members from: a board member and the manager of the Mol Téic (enterprise development organisation), the Local Area Manager within NEWKD (community development organisation), Ireland's distribution system operator (ESB Networks) Dingle Community Engagement Manager, and the MaREI research team. The committee meets regularly on a monthly or sometimes bimonthly basis, in line with the reflexive framework proposed by Polk (Polk, 2015), to manage transdisciplinary research projects. The process of establishing this committee, as well as reflections on the challenges and benefits of the collaboration are covered in detail in Boyle et al. (Boyle et al., 2021b).
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 a number of 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 CO₂ emissions, provided the necessary analysis (McGookin et al., 2021b), and co-produced a report on it with local representatives (McGookin et al., 2020b).
 - 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 5.3.2, there was an extensive community engagement process.

5.3.2 Community engagement process

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 2.A.

Following the review outlined in (McGookin et al., 2021c), 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. 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 CO₂ (McGookin et al., 2021b). 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 (Curtin and Varley, 2017)) 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 the first round of community meetings, participants were essentially given a blank page to outline their concerns and priorities. This posed a serious methodological challenge for the modelling but was a required trade-off to stay true to the participatory process (Section 5.5.3). A brief summary of the community engagements is provided in Table 5-1, for a detailed description please see Appendix 2.A.

A brief summary of the community engagements is provided in Table 5-1. 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 2.A. 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). 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.

Table 5-1. 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 3 rd / 4 th 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

5.3.3 Energy system modelling using LEAP

The energy system was modelled using the LEAP (Low Emission Analysis Platform) software, which is a useful simulation tool for exploring energy scenarios on a local scale (Zivkovic et al., 2016, Heaps, 2012). As outlined by (Nilsson et al., 2020), 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. This facilitates the exploration of scenarios based on questions and proposals raised during stakeholder engagements.

5.3.3.1 Building the LEAP model

As introduced above, LEAP is a simulation-based modelling tool, which means the user defines both the inputs and outputs. The majority of calculations are determined externally in Excel, LEAP then functions as a useful tool to bring the various sectors together, explore variations on model parameters, perform calculations and display results.

There are two central folders to be built in the model: key assumptions (Figure 5-1 left-side) and demand (Figure 5-1 right-side). Key assumptions are the input parameters such as the number of homes or cars, fuel shares and energy demand by technology, and emission factors. These can be directly linked to an Excel sheet as shown in Figure 2.B.1 (Appendix 2.B) or input directly in the model. The determining of future projections (for key parameters like the number homes or cars) is likewise flexible, drawing from Excel or using LEAP features to extrapolate from the base year to an end year value or growing at a particular rate. Within the demand folder, calculations are then setup using the key assumptions data. Figure 5-1 provides an example of the LEAP model structure, showing: branches (yellow folders), key assumptions (blue boxes), technologies (light grey cogs) and environmental factors (dark grey cloud).

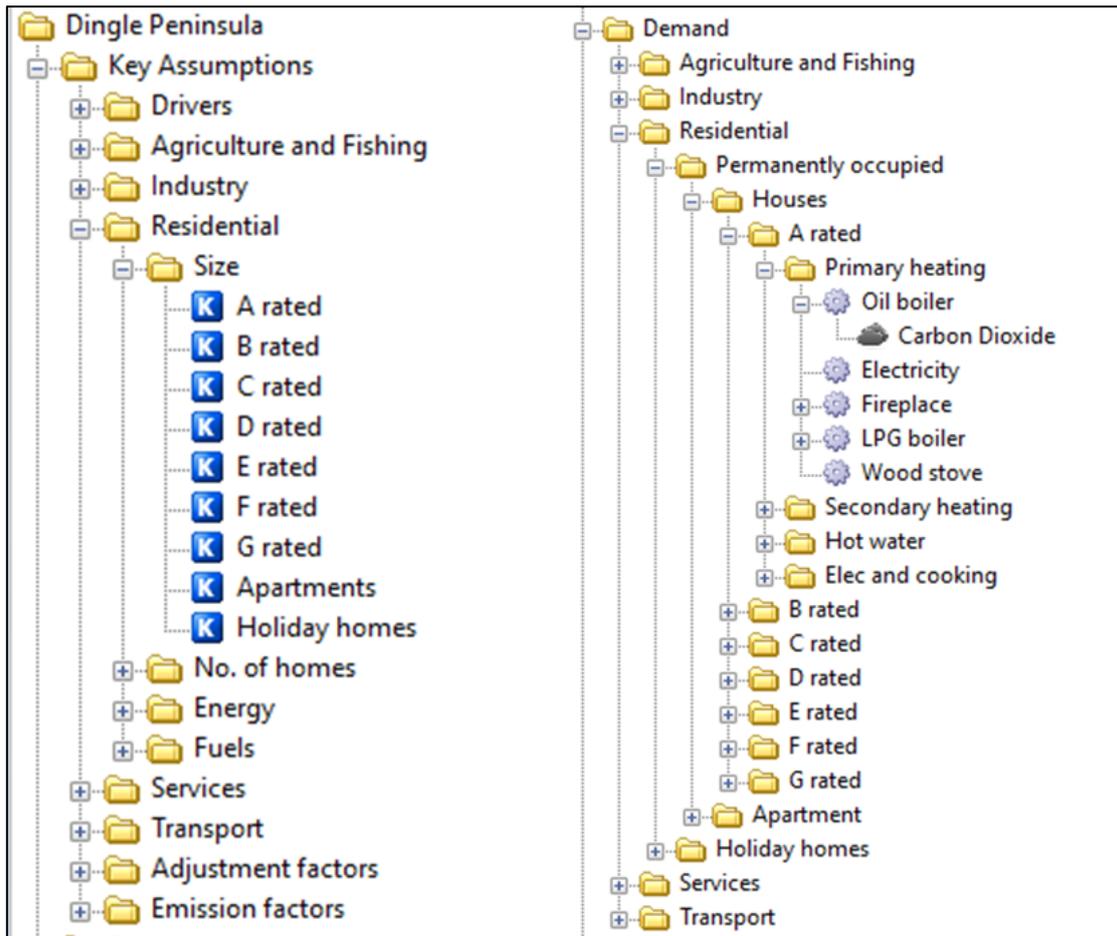


Figure 5-1. Example of the LEAP model structure.

The makeup of the branches in each sector differs based on the data available and intended analysis. For example, in the case of the residential sector, there are four key assumptions folders:

1. Size - Average size of homes by energy rating (as shown in Figure 5-1)
2. No. of homes - Number of homes in each energy rating category (A, B, C, etc.)
3. Energy - Energy demand (kWh/m²) for the different end uses (e.g. primary/secondary heating, lighting) in each energy rating category
4. Fuels - Fuel share for that end use in each energy rating category, e.g. % share of A rated houses using oil for primary heating

The calculations in the demand folder then pull these four parameters together. There are two elements to this: the activity level (Figure 2.B.2) and final energy intensity (Figure 2.B.3). For example, in the residential sector:

$$\text{Activity level} = \text{No. of Homes} \times \% \text{ fuel share} \quad (30)$$

$$\text{No. of A rated homes with oil boiler} = 133 \times 12.6\% = 17 \quad (31)$$

$$\text{Final energy intensity} = \text{Avg. } m^2 \times \text{Avg. } kWh/m^2 \quad (32)$$

$$\text{A rated home with oil boiler MWh per year} = 224m^2 \times 23kWh/m^2 = 5.2 \text{ MWh} \quad (33)$$

$$\text{Energy demand} = \text{Activity level} \times \text{Final energy intensity} \quad (34)$$

$$\text{Subtotal for A rated homes with oil boiler} = 17 \times 5.2\text{MWh} = 87.5 \text{ MWh} \quad (35)$$

To determine energy-related CO₂ emissions, an emission factor (gCO₂/kWh) is then applied based on the technology, e.g. carbon dioxide under oil boiler in Figure 5-1.

For a link to model repository, data sources and key assumptions please see Appendix 2.B. In addition, the potential resource from a variety of renewable energy sources was estimated, in order to assess the contribution to energy security and reducing CO₂ emissions, these calculations are also provided in Appendix 2.B.

The capital cost of mitigation measures was not included. In several cases (e.g. electric vehicles) it would be possible to provide an estimate of the cost to the exchequer based on current grant programmes. However, the actual of cost investing in the different mitigation measures (in particular building improvements), which is what would be of interest to community partners, is difficult to determine. There is very limited data available on the cost of retrofitting different houses or business, and estimates can vary significantly based on building characteristics. It was thus decided to omit investigation of capital costs.

5.3.3.2 Scenarios overview

The implementation of scenarios in LEAP is likewise flexible. It can be done by rerouting the path for key assumptions to different cells in Excel, or within LEAP modifying parameters and the in-built interpolation function. These three methods were each used in the Dingle Peninsula LEAP model:

- The number of holiday homes or homes being retrofitted were varied by updating the links to different projections in Excel, as indicated by the blue text in Figure 2.B.1 (Appendix 2.B)
- The impact of COVID, seasonality of businesses and distance travelled by cars were modelled by adding adjustment factors to the calculations in the demand folder. For example, based on a road traffic counter data on the number of journeys (Transport Infrastructure Ireland, 2022), private car travel was reduced by 24% in 2020/2021.

- Growth in local solar PV was done using LEAP’s interpolation function, which is based on start and end year values (in this case for capacity in MW) as follows: ‘Interp(2020, 0.102, 2030, 0.461)’.

A wide range of measures were modelled in each sector to assess possible pathways (see Table 5-2). 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’ versus a “build forward better” scenario. Table 5-2 provides a brief overview of the scenarios, with particular focus on what happens with regard residential and private cars, two important sectors identified (see Section 5.4.3.1). The mitigation measures explored begin by looking at the impact of national policies (POL scenarios) (Department of Communications, Climate Action and the Environment, 2019), before implementing additional suggestions that emerged from the stakeholder engagements (COPROD scenarios). The differences between national priorities and local perspective, as well as how they were represented in LEAP is outlined in Section 5.4.2.

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 2019-2030 the population would grow at an average annual rate of 0.54%, around half the national average of around 1% (Central Statistics Office, 2017), and similar to the previous 0.51% average annual growth seen between 2002-2016 (Central Statistics Office, 2016a). During the period from 2002-2016, the region’s population grew by 7% compared to a national average of 22% (Central Statistics Office, 2016a) and county-wide growth of 12% (Central Statistics Office, 2016a). 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 2019-2030, which would put the region back in line with county and national projections for that period. As noted in Section 5.3.4, key parameters like these were discussed with local partners but the feedback received was very limited.

Table 5-2. Overview of energy system scenarios modelled for the period 2010-2030

Name		Description
Reference	REF	<p>Business as usual reference scenario with COVID-19 impact</p> <ul style="list-style-type: none"> • COVID-19 impact over 2020/21 • 2022 onward return to business as usual • Population growth is significantly less than national projection for the period 2019-2030 at an annual average rate of 0.45% compared to 1.1% nationally
Current Policy Mid-Range Emissions (Reference Scenario Variant)	REFPOL1	<p>Mid-range emission scenario for national 2030 targets</p> <ul style="list-style-type: none"> • 30% of homes retrofitted to B rating, spread across housing stock. 80% of retrofitted homes get a heat pump. • Private car Internal Combustion Engine (ICE) sales go to zero in 2030, battery electric vehicles make up 50% of sales by 2030 and 20% of car stock, with hybrids and plugin hybrids likewise accounting for 50% of sales in 2030 and 20% of car stock
Current Policy Low Emissions (Reference Scenario Variant)	REFPOL2	<p>Low emission scenario for national 2030 targets</p> <ul style="list-style-type: none"> • Retrofitting targets lowest rated homes (E, F and G), which account for roughly 30% of homes, eliminating this portion of the housing stock by 2030. 80% of retrofitted homes get a heat pump. • ICE sales go to zero in 2030, battery electric vehicles grow to 100% of sales by 2030 and 40% of car stock
Additional measures co-produced (Reference Scenario Variant)	REFCOPROD	<p>Additional measures based on local dialogues</p> <ul style="list-style-type: none"> • Reduced car dependence by 2030: <ul style="list-style-type: none"> ○ Improved public transport replaces 2% of private car kms ○ Active modes replace 5% of private car kms

		<ul style="list-style-type: none"> • Retrofitting targets lowest rated homes (E, F and G), which account for roughly 30% of homes, eliminating this portion of the housing stock by 2030. In addition, minimum post-works energy efficiency target raised from B rated to A rated homes. 80% of retrofitted homes get a heat pump. • Solar PV (4MW farm & 4.5 MW rooftop) installations equivalent to 15% of electricity demand by 2030 • Small-scale wind turbines equivalent to 1.05 GWh installed by 2030 • Solid fuel is banned from 2027 onward, replaced with biomass, which over time comes from local native woodlands • Biomethane from anaerobic digestion replaces LPG and natural gas use in industry, services and homes
Build Forward Better	BFB	<p>Build forward better after COVID-19 impact</p> <ul style="list-style-type: none"> • COVID-19 impact over 2020/21 • 2022 onward build forward better <ul style="list-style-type: none"> ○ 10% of holiday homes remain permanently occupied from 2022 onward ○ By 2030, 25% of holiday homes have become permanently occupied ○ Population grows around 14% between 2019-2030, in line with County/National projections for that period
Current Policy Low Emissions (Build Forward Better)	BFBPOL2	As above in POL2 under reference scenario

Scenario Variant)		
Additional measures co-produced (Build Forward Better Scenario Variant)	BFBCOPROD	<p>As above in COPROD under reference scenario but with additional:</p> <ul style="list-style-type: none"> • Reduced car dependence by 2030: <ul style="list-style-type: none"> ○ Improved public transport replaces 5% of private car kms ○ Active modes replace 7.5% of private car kms ○ Work from home 2 days a week for employees that this would be suitable, around 40% of the workforce. Replaces 7% of private car kms. • Retrofitting target left at B rating for lowest rated homes undergoing works. To reduce impact of growth, 520 C/D rated homes upgraded to A, equivalent to number going from holiday homes to permanently occupied.

5.3.4 Relationship between stakeholder inputs and energy system model

As further outlined in Section 5.3.2, the findings from the community engagement provided some elements of the scenarios (see in particular Table 5-4). 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 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. Pedde et al. in developing a framework to understand the implications of

societal capacity across the five global shared socio-economic pathways (SSPs), highlight that social equality is as important as technological development in achieving the 1.5 °C target (Pedde et al., 2019). 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 techno-economic 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 can highlight more informed policy interventions. Some of the key discussion points raised during the community meetings will be outlined in Section 3.1 with reference to wellbeing indicators identified by the participants. Following the definition of (Dodge et al., 2012, p. 230), wellbeing here is seen as *“the balance point between an individual’s resource pool and the challenges faced”*. As outlined by La (La Placa et al., 2013, p. 116), framing wellbeing beyond 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”*. 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.

5.4 Results

This section is broken into three parts. Firstly, we reflect on the area’s societal capacity to deal with these challenges in light of the findings of the community meetings. Then secondly, the translation of the community engagement into the energy system model is discussed with reference to key issues that were(/n’t) represented in LEAP. Thirdly, an overview of the energy scenarios and associated CO₂ emissions is provided, highlighting the decarbonisation challenges in light of previously outlined findings.

5.4.1 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 2.A, while the full set of notes recorded during the two rounds of the community meetings have been published online (Ó Caoimh and McGookin, 2021b), (Ó Caoimh and McGookin, 2021a), along with a summary learning brief that was co-produced with local partners (McGookin et al., 2021e). The publishing of the raw

data and sharing with those who attended was seen as an important element of transparency. Table 5-3. 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. Building on the initial investigation, through the ‘Re-Imagine Dingle Peninsula’ workshop seven working groups were formed around key projects: 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 community meetings held.

Table 5-3. Summary of common issues and projects discussed during the community meetings held in November 2019 and February 2020.

<p style="text-align: center;">Common Issues, 1st Round, November 2019</p>	<p style="text-align: center;">Proposed Interventions, 2nd Round, February 2020</p>
<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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

<ul style="list-style-type: none"> • Reduce reliance on imported fossil fuels in favour of locally available renewables 	<ul style="list-style-type: none"> • 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
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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, these (un)sustainability issues are exacerbated by the fact that regional, county and indeed local development plans do not adequately reflect the concerns and priorities of the community. In fact, in some cases the current challenges facing the case study region in ‘overtourism’ and population decline are direct consequences of national, and subsequently, regional and county policy objectives (McGookin et al., 2021e).

There was a lot of frustration at the limited access to housing driven by the National Planning Framework’s priority of ‘compact growth’ (Government of Ireland, 2018), 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., 2021), much of rural Ireland suffers from forced car ownership due to the limited availability of public transport alternatives. 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 petrol or diesel cars, 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 Figure 5-2 below) has just a single service on a Friday connecting to the county capital, which is located just outside where the peninsula meets the mainland.

The wellbeing indicators seen in Figure 5-2 provide a useful overview of the issues identified during the community engagement process. It compares 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 65s, 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 county and country. The majority of values are based on the Census of Population of Ireland taken in 2016, as that is the most recent currently available (Central Statistics Office, 2016a).

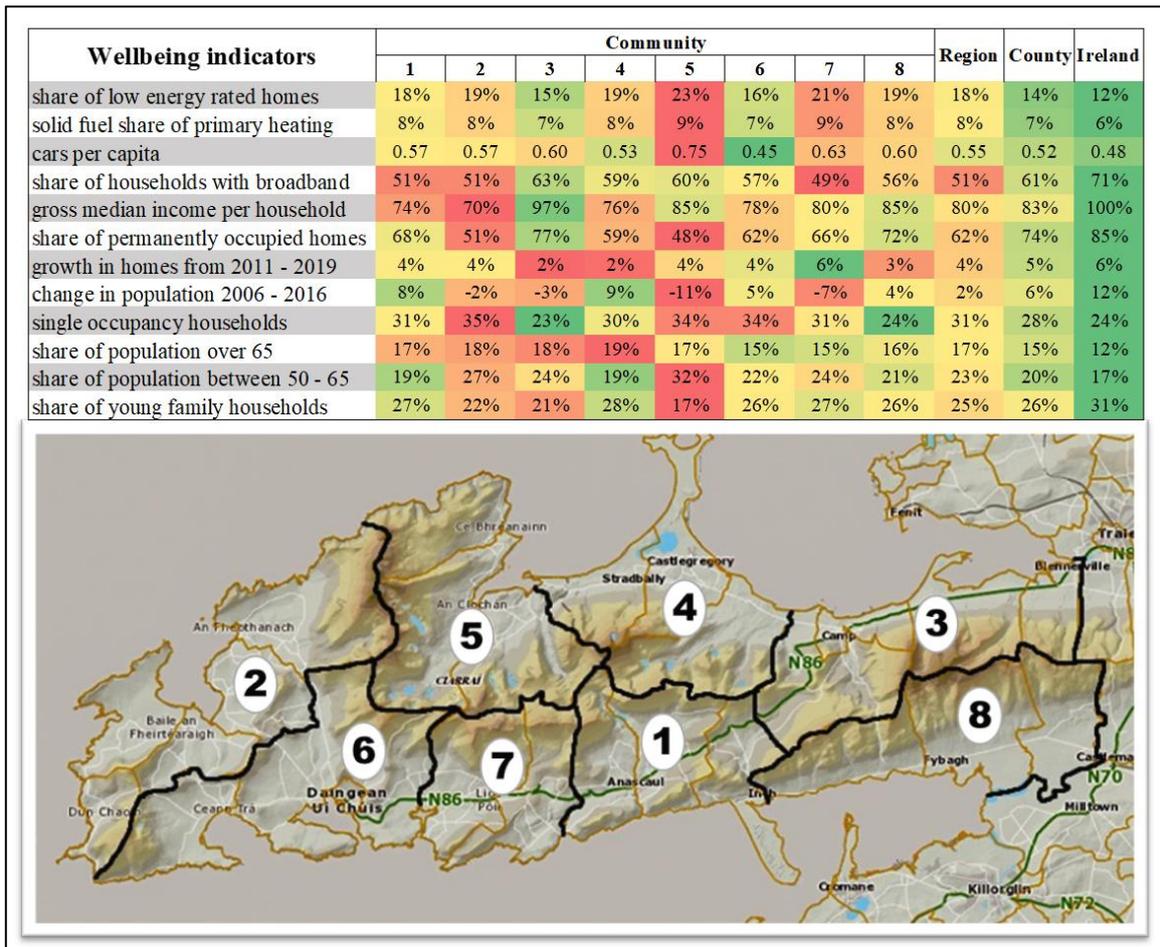


Figure 5-2. Wellbeing indicators identified in the 8 communities that make up the case study region compared to county and national figures (CSO data 2016), along with a map indicating the location of the communities.

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 Figure 5-2) between the mainland and the largest town in the area (Community 6) being left behind. Moreover, looking at the challenges facing the area in a broader approach like this highlights some key concerns. 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 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.

5.4.2 Translation of community input into energy scenarios

As introduced in Section 5.3.4, a key methodological challenge in the present study was the link between the findings from community engagements (Section 5.4.1) and the energy system model developed (Section 5.4.3). 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 5-4.

The fact that the scenarios informed by local interests achieve the lowest emissions savings (Section 5.4.3) 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 internationally (Byrne, 2017), 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.

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 2.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.

Table 5-4. 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Focus on private cars switching to electric vehicles • Active / public transport neglected, particularly in rural areas 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Focus on wind and solar • Heat and transport options other than electrification neglected • Favours large-scale developments • Limited supports available for 	<ul style="list-style-type: none"> • 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 	<p>~10% renewables by 2030</p> <ul style="list-style-type: none"> • Large uptake of solar PV on households, farm sheds, schools, etc. • Native woodland crop developed for secondary home heating • Small scale anaerobic digestion plant

	small/ micro-generation		provides biomethane resource to replace LPG
Holiday homes	No clear policies in place	<ul style="list-style-type: none"> • Some communities ghost towns in winter • Extremely limited long-term lets available 	<p>Within BFB scenarios:</p> <ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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

		causing traffic issues and poor air quality	impact not considered
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5.4.3 Energy scenarios

5.4.3.1 Reference scenarios modelled

To get an overview of the decarbonisation challenge, Figure 5-3 shows the energy-related CO₂ 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 CO₂ emissions. Assuming that key drivers of per capita CO₂ 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 CO₂ emissions associated with such a rebound are projected to be 8% higher by 2030.

The two key sources of emissions across both scenarios are private cars and households, which account for the majority of energy-related CO₂ emissions in 2030 at about 65%. As previously outlined in (McGookin et al., 2021b), 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 2010-2019 due to the significant fall in the electricity grid's CO₂ intensity, which nearly halved from 550 gCO₂/kWh in 2010 down to 324 gCO₂/kWh by 2019 (Sustainable Energy Authority of Ireland, 2021a). Otherwise, CO₂ emissions from fossil fuels are projected to remain stagnant over the period.

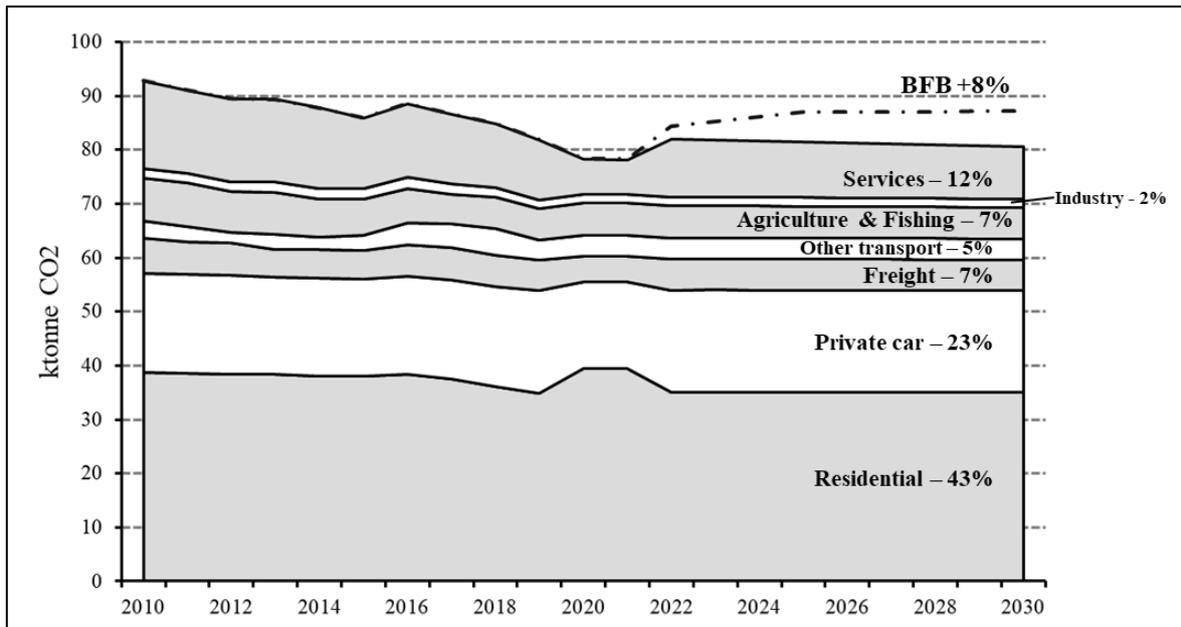


Figure 5-3. Dingle Peninsula energy related CO₂ emissions by sector in the reference scenario 2010-2030 and projected increase in the build forward better (BFB) scenario.

5.4.3.2 Energy related CO₂ emissions by sector and fuel in the scenarios modelled

As outlined in Section 5.3.3, 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 CO₂ emissions highlighted in Figure 5-3, particular focus was given to those sectors.

Figure 5-4 gives a breakdown of the energy related CO₂ in 2030 compared to a 2018 reference year for the seven scenarios outlined in Table 5-2 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 2021-2030 (Department of the Environment, 2021a). It should be noted that this is essentially 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 between 2021-2030 (Department of Communications, Climate Action and the Environment, 2019).

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 CO₂ 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 CO₂ 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. 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 CO₂ 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.

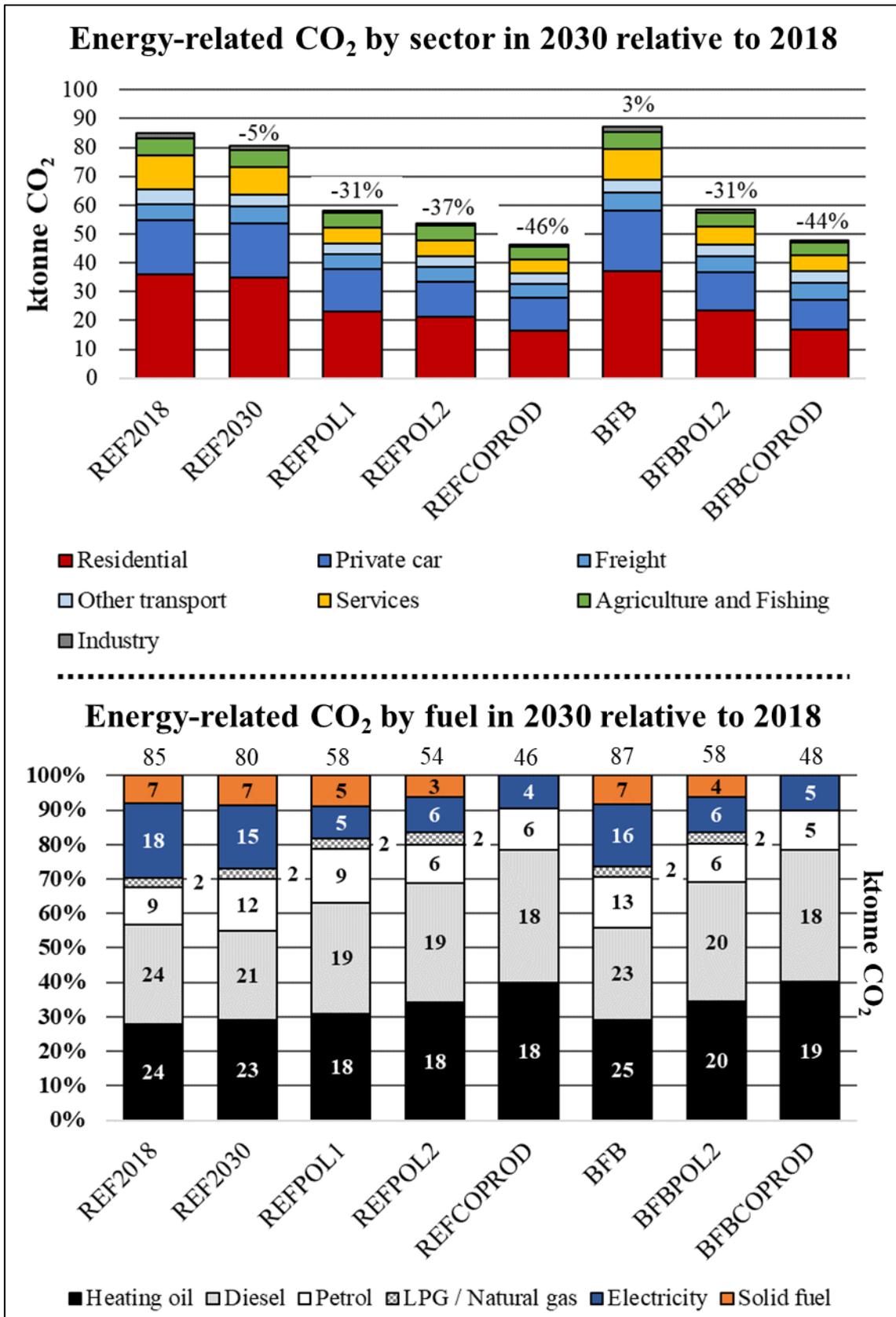


Figure 5-4. Energy related CO₂ emissions on the Dingle Peninsula by sector (top) and by fuel (bottom) for the end year 2030 in the eight scenarios modelled compared to reference year 2018.

5.4.3.3 Renewable energy contribution

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 description in Appendix 2.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. An overview of the renewable energy technologies considered is provided in Table 5-5..

Table 5-5. 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	4.3 GWh
Wind energy	3 x 4 MW turbines	29.4 GWh
	80 x 5 kW pole-mounted microturbines	1.05 GWh
Small-scale hydro	530 kW from 6 turbines ranging from 30 – 180 kW	2.4 GWh
Bioenergy	Biomass - 1,000 ha native forestry	8.2 GWh
	Anaerobic digestion	10 GWh

Figure 5-5 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 11-12% 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 transformation.

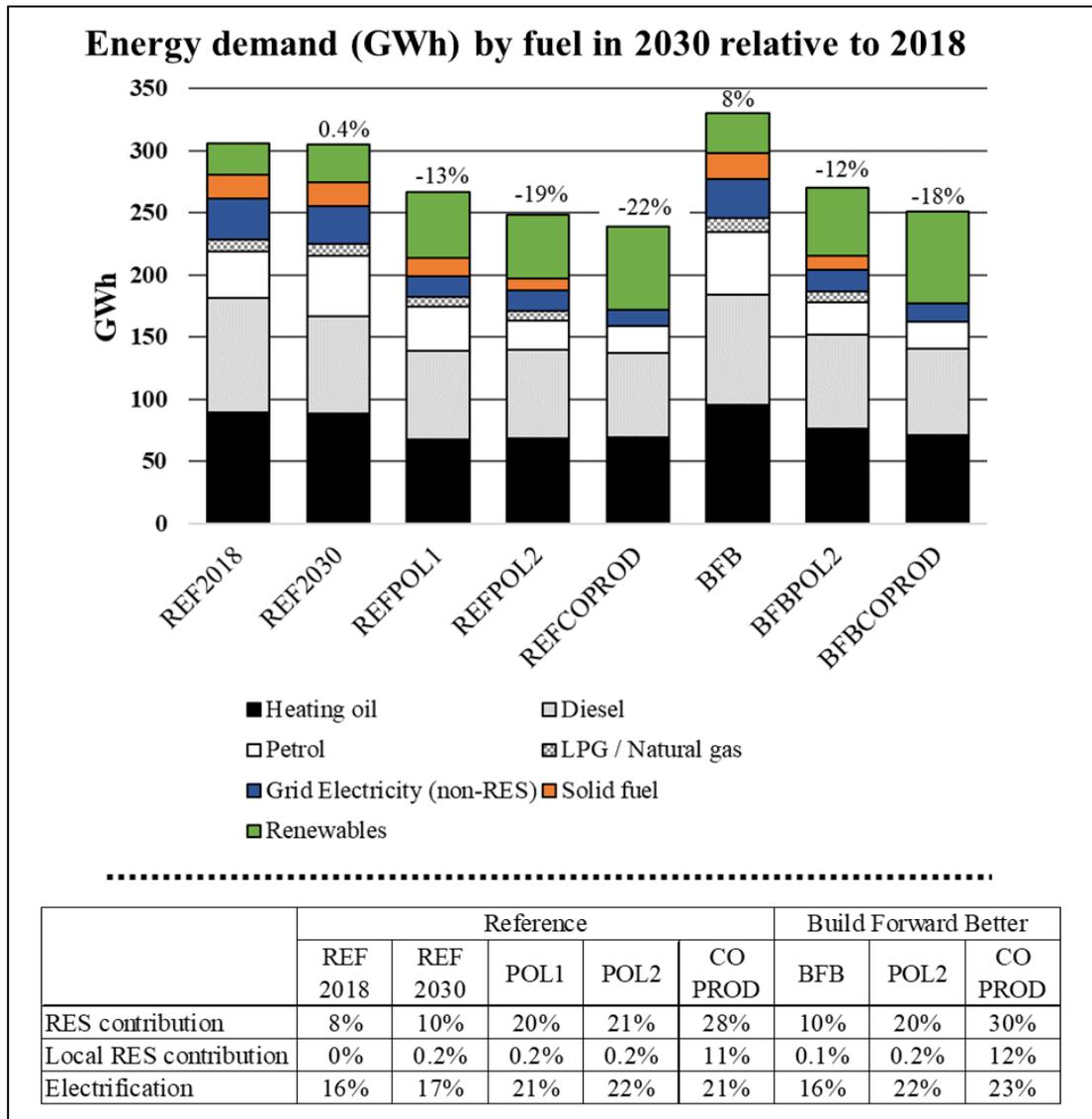


Figure 5-5. Energy demand by fuel on the Dingle Peninsula for the end year (2030) of the seven scenarios modelled compared to base year (2018).

5.5 Discussion

5.5.1 What did the co-production approach tell us about the energy system model?

The most valuable learning from the co-production approach is the differences between the *messiness* of the real-world compared the more 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 5.5.3) but most 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 5.4.1. This context is crucial to identify barriers and develop an understanding of to implement the necessary measures. For example, looking at housing, the energy system model clearly shows a 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 CO₂ 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 is clear but actually realising them will require more careful policy planning. As illustrated in Section 5.4.1, 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 5.4.3.2, achieving Ireland's GHG emission reduction target for 2030 will require a dramatic and rapid change to our energy system. The findings of this study highlight that in order to ensure this is done effectively through a fair and just manner, new communication channels and forms of decision-making that bring together a diversity of stakeholders at a local and national level are needed.

5.5.2 Learnings from the energy system model

In addition to the broader societal considerations offered by the participatory process (Section 5.5.1), the energy system modelling exercise itself provides important insights. Firstly, the scale of the challenge is laid bare when dealing with such a small rural area. Secondly, while high-level national ambition like retrofitting 450,000 homes by 2030 is important, the pathway

to actually delivering it requires more careful consideration. Thirdly, highlighting the gap between the community objective of energy independence and emissions pathways.

As previously outlined in Section 5.4.3.1, home heating and private travel are key issues. For home heating, the results demonstrate the need to consider which houses are being retrofitted and dealing with secondary heating. The reduction in residential sector within REFPOL1 when the retrofitting target evenly spread across the stock is 36%, whereas in REFPOL2 with low rated houses improved it is 41%. Having addressed the lowest rated homes, one key source of emissions left is the roughly 5 ktonne CO₂ (~25% of CO₂ emissions in the sector in 2030 under REFPOL2) associated with 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. With regards private travel, the results show that electric vehicles (the central focus of national policy) will not be sufficient, and thus calls for more transformative efforts such as active modes and public transport, which until recently had been neglected by national policy.

What is most striking about the results is that the highly ambitious COPROD scenarios modelled for the case study region result in a 44-46% reduction in 2030 relative to 2018 (Figure 5-4), which falls short of the national target of 51% reduction in 2030 compared to 2018 (Department of the Environment, 2021a). Given that this target applies to all greenhouse gases, with energy expected to exceed it in order to accommodate a less significant reduction in non-energy emissions from agriculture, it is even further short of what is needed. These results clearly highlight that existing policy measures do not match emission reduction targets, and that is before even considering the broader societal issues outlined in Section 5.5.1. It should be noted that the scenarios modelled are based on the previous National Climate Action Plan 2019, which was updated at the end of 2021. However, there was very little change in the key targets referenced here for retrofitting, heat pumps and electric vehicles despite the significant increase in emission reduction ambition.

Just as the participatory process shines light on the limitations of the energy system model (Section 5.5.1), the technical analysis likewise points to contradictions and tensions within the community objectives. As noted in Section 5.4.3.3, the local renewable energy contribution is expected to be limited at only 11-12% of energy demand in 2030 in the most ambitious scenarios, which is a long way from the aspiration of energy independence. If that goal is to become a reality, difficult decisions need to be made on the placement of much larger energy developments than what is currently deemed acceptable. Another key tension is the desire for

significant growth in population while at the same time reducing emissions, as illustrated by the increase in emissions within the build forward better scenarios (Figure 5-3).

5.5.3 Reflections on the co-production approach

A key challenge faced by transdisciplinary research projects is the ambition of contributing to societal change (Polk, 2015), and the balancing of scientific legitimacy with the process (Köhler et al., 2019). This need to demonstrate ‘success’ often means that useful learnings from project failures are not discussed (Collins, 2020). However, in order to support the development of co-production approaches it is important to outline failings (Lemos et al., 2018). One key difficulty in the present study was the very flexible and adaptive approach taken to maximise stakeholder input on the research design process (Sections 5.3.1 & 5.3.2).

As introduced in Section 5.3.2, 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 (Watson et al., 2019a). 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 (North East West Kerry Development, 2021). The unstructured nature of the participatory process made it very difficult to translate into the energy system model (as has been previously noted (van Vliet, 2011)), 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 (Pohl et al., 2021), 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 (Genus et al., 2021), 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. As partners in the project it is important to build relationships, which requires humility and time to build up trust. However, having established a good relationship then makes it difficult to manage expectations, and fosters a reliance. 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 transition underway. Moreover, a co-production approach rightly seeks to achieve real-world impact and support local needs 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?

5.5.4 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 5.4.3, 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 CO₂ 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 CO₂ emissions, it would be important to include non-energy greenhouse gas emissions such as those in the agricultural sector, particularly in rural areas. A final piece missing from the energy system model would be to include the fuel costs associated with the various scenarios and capital cost of mitigation measures.

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 and Sweeney, 2012) highlights that by share of land area at risk to sea level rise, the case study's county is Ireland's fourth most vulnerable. Climate change mitigation and adaptation are rarely discussed together, but when working on the local level like in this present study, it is clear that it would be useful to explore the trade-offs and co-benefits.

With regards the co-production approach, 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 local 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 beyond 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.

5.6 Conclusion

This study has provided reflections on a co-production approach to energy system modelling. It follows a three-year participatory action research process, which involved extensive stakeholder engagement to shape the research process and provide insights to inform the energy scenarios developed for the case study region. It has demonstrated that there is value in opening up discussions on sustainability/resiliency in a broader sense of the word than what is usually facilitated in energy system modelling processes. While the energy system modelling exercise has also raised important questions of national policy and community objectives. From these results we can see the dialectic, and thus, complementary nature of the two areas of analysis.

With regards the co-production approach, collaboratively agreeing a research plan posed a serious methodological challenge for the energy system modelling but 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 channels of communication 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 5.5.3, there remains some unanswered questions about the evolving role of research and what a co-production approach should entail. We would advise against the slipping of research into community development roles, but it is clear that there is an important facilitatory 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 may help with the necessary improvement in communication channels between bottom-up / top-down stakeholders to support the development of well-informed policy that can deliver the significant transformation required.

Chapter 6 Discussion

6.1 Key learnings

6.1.1 The ongoing challenge of integrating participatory methods in energy system modelling and planning

A key finding of Chapter 3 was that a limited amount of studies involved collaborative approaches aligned with established transdisciplinary principles (Lang et al., 2012). It was striking that a third of studies involved a once-off engagement with stakeholders, and only a few allowed participants to feedback on the results of the energy system model developed. This leaves the design of the research, interpretation of the stakeholder inputs, translation into energy system modelling parameters and validation of the results within the control of the research team. As outlined in Section 3.3.1 using the conceptual framework developed, this doesn't constitute a meaningful engagement process as much of the control still lies in the hands of the experts. Another trend was that studies often limited stakeholder inputs to preferences on predefined energy system configurations in order to translate them into quantifiable model parameters. This is necessary to deal with this key methodological challenge (Section 3.6.2.1) but omits an understanding of the broader context within which those decisions need to be framed and may limit discussion to the *optimal* technological solution rather than a broader debate on what constitutes a desirable future (Castree et al., 2014).

The majority of stakeholders came from academic or environmental/energy backgrounds, with very few studies seeking to reach 'beyond the converted'. These groups offer important expert knowledge to tease out well-informed solutions to the problem. However, they are unlikely to represent the wider public opinion. As outlined in Section 2.3.1, dealing with the complexity of contemporary wicked problems necessitates public policy to involve a diverse group of stakeholders. This requires authentic dialogue (as set out by (Innes and Booher, 2010) to unpack areas of conflict and disagreement in order to work out the way forward.

The balancing of open deliberation and quantitative modelling remains an unresolved challenge. As discussed in Section 5.2& 5.3, having identified the need for a broader debate alongside the energy system modelling process, the approach adopted sought to bridge rather than merge analytical methods, in line with suggestions from (McDowall and Geels, 2017) and (Geels et al., 2016). The investigation was guided by a participatory action research approach

that sought to maximise local involvement. Working with a community development organisation was seen as important to reach a broad representative audience instead of just speaking to people interested in climate and energy issues. This resulted in a very rich community engagement process but was not easily translated into the energy system model developed.

As noted in Section 5.5.3 & 5.5.4, although facilitating feedback on the model parameters and results was seen as important, it proved difficult. While the community engagement provided valuable context within which to frame the analysis, much of the control over what came out of the model remained in the hands of the research team. Another consideration was what happens to the model once the research has ended. Effort was made to work with the community energy group from the case study region on ways to handover the model and ensure the results remained usable, but this was too much of a time commitment for the volunteers involved. This highlights the value of simplified computer tools for representing modelling results as discussed in Section 3.5.1.4 but also begs the question if such models are the support needed?

The conceptual framework developed (Section 3.3.1) provides a clear illustration of what a meaningful engagement process involves, but actually putting it into practice has presented more questions than answers. The results of Chapter 5 and contributions of this thesis (Appendix 3.A) have demonstrated the benefits of a collaborative approach to energy system modelling. However, it also stands to highlight the limitations of quantitative modelling tools, messiness of the real-world, and a new evolving role for research. A number of suggestions for further investigation are discussed in Sections 6.4.1 & 6.4.4.

6.1.2 Importance of data granularity and the lived experience

In the absence of reported energy data below the national level, estimating subnational energy demand and supply relies on either downscaling national values using energy usage indicators or by constructing building and car stock models (as outlined in Chapter 4). The data that these methods use often lacks temporal and spatial granularity. The demographic and socio-economic indicators that come from Census data are generally only updated every five years. In the case of building stock data, the poor-quality reporting and lack of representativeness of energy benchmarks are well-documented (Dineen et al., 2015), (Droutsas et al., 2016), (Li et al., 2019). This challenge is at odds with the fact that having a clear understanding of the energy

system and regional characteristics is a vital first step in the energy system planning process, as demonstrated by the results of Chapter 4 (Section 4.6).

Some suggestions for how future research may improve these data gaps are discussed further in Section 6.4.2. One of the key learnings from dealing with this challenge, is the value of the collaboration with local stakeholders. Being a member of the steering committee setup to coordinate the development of an energy plan facilitated a mixed methods approach with people who had a good understanding of the area assessing the results of the analysis (McGookin et al., 2020b), (McGookin et al., 2020a). While a set of criteria was developed to compare the energy usage indicators in each sector (Section 4.6.1), much of the decision making still relies on modeller judgement. Although it does not offer a definitive means to verify the results, comparison to the lived experience of local stakeholder enhanced the robustness of the analysis. Similarly, in Chapter 5, during the first round of community meetings (Appendix 2.A), questions were posed to determine if the data matched the experience of those living in the area, which yielded a valuable combination of statistical and anecdotal evidence.

6.1.3 Appreciating the messiness of the real-world

Returning to the third research question (Section 1.2) on the prospect of modelling the broader societal transition or stakeholder preferences in quantitative energy system modelling tools. 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, it is clear 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 (Li et al., 2015), (Holtz et al., 2015), (Köhler et al., 2018). However, this reductionist approach risks oversimplifying the messiness of the reality within which the energy system must be placed and is thus inappropriate.

As noted in Section 5.5.1, it is important to appreciate the complexity and messiness of the real-world in order to develop effective climate and energy policy interventions. Firstly, there is the question of current (un)sustainability challenges across environmental and social domains, and what is driving them. As explored in 5.4.1, the socio-economic and demographic

challenges facing the case study region in housing, employment, wellbeing and an aging population means the capacity to respond to the climate crisis is limited. This calls for a broadening of our understanding of a desirable future beyond just the technical changes to the energy system.

Secondly, there is the question of who can pay for the energy transition. Ireland's decarbonisation strategy at present relies heavily on individual households making the investment in an electric vehicle or retrofit. This is excluding a large portion of the population who do not have the resources and capacity to access the grant supports, which poses a serious equity and distributional justice issue. As (Social Justice Ireland, 2021) highlight "*these subsidies are functioning as wealth transfers to those households on higher incomes while the costs (for example carbon taxes) are regressively socialised among all users*". Under current policy, it seems likely that the gap between rural and urban populations demonstrated in Section 5.4.1 will worsen with the houses most in need of energy improvements (offering the most significant CO₂ savings, Section 5.4.3.2) unable to make use of grant supports. This will leave rural communities feeling discarded and thus rightly frustrated, which will make issues like the carbon tax and placement of energy infrastructure increasingly divisive. Thus, posing a significant risk to decarbonisation efforts. As the example provided by (Mullally and Byrne, 2015) in Section 2.2.2 highlighted, feelings of injustice can be a key driver of public opposition.

More open and transparent dialogue is needed to explore tensions between local and national priorities in order to develop well-informed policy. This would necessarily be a two-way process as co-benefits are not always guaranteed. There will be instances where higher-level policy decisions can be aligned with local needs but there will also be trade-offs and difficult issues that need to be resolved. In line with policymakers being more informed of 'on-the-ground' issues, local stakeholders and groups must likewise appreciate key constraints policymakers are trying to juggle. It is only from such a point of mutual understanding of both the problem and available solutions that an agreement on the best path forward can be reached.

These difficulties point toward 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 (Curtin and Varley, 1995), (Curtin and Varley, 1997), but if not, then it risks becoming an increasingly divisive issue.

6.1.4 The value of a transdisciplinary research approach

6.1.4.1 Establishing and coordinating a local committee

Very early in the project, following established best practice (Lang et al., 2012), our research team identified the need for a committee to coordinate activities in the area (Section 2.6). However, reaching consensus on a collaborative partnership was not a simple process. There was initially a lot of tension between our local non-profit partners and the national distribution system operator (ESB Networks) because of the very different financial situations. There was a perception that ESB Networks must have a lot of money available, but in reality, the project budget was very tightly controlled and vast majority of it spent on the technology in the trials (home retrofits, solar PV, heat pumps and electric vehicles). The local groups were disappointed by the very limited resources offered to them, which was particularly contentious because ESB Networks had sought discounts on the office they rented in the remote workspace run by one of the local partners (Mol Teic). Following this bumpy start, it took time before the different stakeholders build up an understanding and could see the value of working together. A key issue was the fact that the geographical area of interest didn't align since ESB Networks the 'Dingle Project' was looking at a region within around half the peninsula. Similarly, two central projects of interest for Mol Teic are anaerobic digestion and public transport but ESB Networks are focused on heat pumps and electric cars. Moreover, it must be acknowledged that working on such an initiative is currently outside the remit of Irish community or enterprise development organisations. This put a serious strain on the time available to our local partners. MaREI's 'Engaged Research Support Officer' (a new role created for this project) took the lead in bringing together the group and has coordinated it ever since. This has been a valuable contribution but raises questions over how it may evolve once the research involvement ends. ESB Networks' Dingle Project will end in December 2021, and as of September 2021 MaREI capacity has been significantly reduced. There is a clear need for sub-county coordination as is emerging from this project but exactly who takes responsibility for setting these up remains unclear.

6.1.4.2 Benefits of collaborating with local (community) stakeholders

Returning to some of the literature outlined in Section 2.2& 2.3, and the central goal of this thesis to develop participatory methods in energy system modelling and planning, there have been three key benefits from the collaboration with local stakeholders:

- Trust in actors – Collaborating with local stakeholders provides access to networks, and more importantly, their existing relationship within the community can be a huge strength. This helps to overcome the distrust of outside actors that may spark public opposition (Graham et al., 2009), (Devine-Wright, 2013), (Mueller, 2020), (Hall et al., 2013), (Ceglaz et al., 2017). The roughly 400 attendees at the community meetings (5.3.2) and rich findings in Table 5-3. is a testament to the work of the community development organisation we partnered with. With an increasing interest in participatory methods to energy system modelling and policy planning, it is important that researchers and practitioners avoid ‘re-inventing the wheel’ and make use of such existing expertise and experience.
- Procedural fairness - Facilitating input on the research design with a governance committee is important for three reasons. Firstly, it ensures an open and transparent process throughout the research cycle, not just during a particular engagement stage. Secondly, it keeps the questions that the research seeks to address open, which is an essential element of ‘authentic dialogue’ (Innes and Booher, 2010). Finally, by doing so it produces outputs of use to the stakeholders involved and thus can have real-world impact, discussed further in the next point. However, as noted in Section 5.5.3 & 6.1.1, this comes with a trade-off. In the case of this thesis, the content of the workshops was agreed with local partners, which meant it was left very open as opposed to the original plan to have dedicated exercises on the energy system (as identified in Section 3.5). The outputs were thus not easily translated into the energy system model developed.
- Usable knowledge – an inherent characteristic of the co-production approach is that the research is part of an active and evolving project. This is noted as important in the literature given the urgency of (un)sustainability issues, research must contribute to action (Table 2-6.). Beyond this, as suggested by (Fazey et al., 2018, p. 65), what they define as ‘second-order experimentation’ in this manner seeks to “*capitalise on the opportunities for learning provided by interventions that are already happening and more quickly feed this back to enhance action*”. One of the key considerations emerging from the *Corca Dhuibhne 2030* project is how the gathering of learnings and reflections on the very practical issues encountered on a day-to-day basis within the cases study area may inform actions elsewhere (Appendix 3.A).

6.1.4.3 Benefits of collaborating with the social sciences

First and foremost, collaboration with the social sciences offers useful practical knowledge and experience in qualitative data gathering techniques such as surveys, interviews, workshops, etc.

Coming from social science backgrounds the researchers have inevitably worked with qualitative methods before and can help with both the design and implementation of such activities. As was noted in Section 5.6, it's important that technical experts looking to move into this space make use of existing expertise and benefit from the breadth of knowledge already available. Social scientists can provide valuable insights into best practice and how to carefully plan a public engagement process.

The approach adopted in this thesis benefitted significantly from lengthy debates between technical and social expertise. Many of the calls for a new approach to engineering (Section 2.3.2), public participation (Section 2.2) and policy planning (Section 2.3.1) are decades old, yet dominant approaches remain predominately technocentric. The need for more 'cross-fertilization' between diverse fields of knowledge is nevertheless clear. Informal settings like travel to and from the Dingle Peninsula, although a time burden (for remotely based researchers), also provided an important opportunity to build a better understanding among the research team, and in the context of this thesis, to have an honest debate on the respective merits of approaches that would seek to merge or bridge the community engagement and energy system modelling process.

On a personal level, meaningfully collaborating across the disciplines exposes researchers to differing worldviews and conceptualizations, which helps to make one more conscience of your personal values and bias. This reflective self-awareness is essential to the honest researcher role outlined in Section 6.1.5. As noted by (Caniglia et al., 2021), modellers must have humility with regards the limitations of their own knowledge, as well as their hidden biases, in order to have respect and empathy for others and their viewpoints. Being challenged by other fields of knowledge, facilitates a critical reflection on the engineering discipline and its place in society. It raises questions of how engineering practices may be supporting or hindering progress towards vital (un)sustainability challenges such as the low carbon transition, from which we can look to find new improved ways of working.

6.1.5 The role of the honest researcher

As discussed in section 5.5.3, within transdisciplinary research literature, there has been much discussion on the variety of different roles a researcher must adopt (Lang et al., 2012), (Wittmayer and Schöpke, 2014), (Pohl et al., 2010). One overarching role that has emerged through this investigation is that of the 'honest researcher'. It challenges and builds on Pielke's role for science in policy as '*The Honest Broker of Policy Alternatives*' (Pielke, 2007), and

with regard engineering practice, strengthens Beder's suggestion of a more public role for the engineer in policy planning (Beder, 1998). The elements to the honest researcher role adopted in this thesis may be summarised as follows.

- The expert – A central component is to offer expertise in a particular field. Within this thesis that involved conducting technical analysis on the current state of the energy system (Chapter 4) and developing scenarios for the future (Chapter 5). However, exactly what the expertise is will depend on the area of interest and it should be noted is of course not limited to technical analysis, as it may involve those from the social sciences.
- The communicator – Communicating the decarbonisation challenges and solutions at a number of levels (Figure 2-1), for example: public events, workshop discussions, policy briefs, newspaper articles, etc. A key part of the approach in this thesis, there is the additional consideration for how the technical analysis informs the work of project partners by providing expertise and advice as a member of steering committees. While local knowledge is important to understand the real-world transformation process, it is also important that people have an opportunity to engage with energy/climate experts to ensure solutions are well-informed.
- The listener - Listening to local experiential knowledge and taking it on board. This role sees the need to be receptive of conflicting and contrasting opinions in order to build a broader understanding of issues. It is an important addition to the communicator role above, which would be along the lines of conventional scientific outreach roles seeking to educate or inform the public.
- The coordinator - The establishment and coordination of a local governance structure as is necessitated by the research approach (Section 2.6 & 5.3.1). In this case, the role was primarily filled by MaREI's Engaged Research Support Officer and was a significant contribution to the wider project.
- The facilitator – facilitating discussion and debate on the best path forward. As outlined in Chapter 3 and demonstrated in Chapter 5, there is a need to open up the energy system modelling and planning process to a more diverse group of stakeholders. Technical experts have an important role to play in these engagements with proper training in facilitation and deliberation.
- The bridge builder - Transdisciplinary researchers are uniquely placed when given the opportunity to work both on-the-ground in local transformation processes and also feed into policy at higher levels. This may help to bridge the communication gap between local

communities and national policy objectives (Sections 5.4.1 & 5.5.1), supporting well-informed policy measures.

- The reflective practitioner – Contra to Pielke’s suggestion that the researcher can be a detached objective observer, the honest researcher works from within the problem. Thus, explicitly recognising and embracing the reality of personal bias. Essential to the credibility of the honest researcher is an openness, humility, and honesty about their personal values and worldview. The researcher’s advice is recognised as being framed through their eyes. In addition, to support further development of the field, it is important to critically reflect on the approach taken to identify learnings for future practice (Section 5.5.3), the positioning of transdisciplinary research in higher education and more broadly on the role of research in society.

The value of the honest researcher role is demonstrated by the contributions of this thesis across science, society and policy (Appendix 3). However, it is not without its challenges and questions must be asked about the new role (6.4.3).

6.2 Contributions of this thesis

This section focuses on the scientific contributions on the thesis, the significant contributions to society and policy are outlined in Appendix 3.

6.2.1 Open data

As (Weinand et al., 2020c, p. 15) highlight in their review of local energy system models “*there is a general lack of transparency across most reviewed literature, meaning that neither open data nor open models are widely applied to local energy systems*”. Throughout the papers that formed chapters of this thesis great effort has been made to publish the methodology and associated data.

In the case of Chapter 4, the accompanying Data in Brief article ((McGookin et al., 2021a)) supports both practioners and researchers seeking to understand the current energy demand and supply in their region, city or town by clearly outlining the energy usage indicators that were available for this study, which was a prevalent weakness in literature to date (as discussed in Chapter 4). On from this, it offers an important area for future investigation. Internationally, a comparison of this data against other countries would give valuable insights into the representativeness of the various energy usage indicators and varying energy profiles of

different countries. Within Ireland, with improvements in the granularity of data, the differences across regions would be an interesting area to explore.

Similarly, in the case of Chapter 5, the model, description and data have been openly published on the data repository GitHub. This ensures that the results of the analysis are easily replicable and may inform future research in the area. It facilitates further development on some key considerations that could not be included in the present study, as outlined in Section 5.5.4.

6.2.2 Frameworks developed

This thesis is uniquely placed, attempting to bridge two complementary (as demonstrated throughout this thesis) but nonetheless very different fields of knowledge and practice: computer-based energy system modelling and human-based participatory methods.

Firstly, to understand what a meaningful integration of these two fields would entail, a conceptual framework for the quadrangle of energy policy balancing security of supply, environmental impact, economic viability, and social acceptance was produced. This was based on a previous proposal from (Schubert et al., 2015) and developed further in the context of an energy system model building process. It clearly defines the minimum requirement for a participatory approach and highlights the value of a collaborative/co-production approach as articulated throughout this thesis.

A key technical contribution of this thesis is the framework developed for determining energy demand and supply below the national level (Chapter 4), which addresses a blind spot in the literature to date. While there are a large number of studies on subnational (region, city or town) energy systems, the process of determining an initial estimate of CO₂ emissions before making projections into the future is often not given sufficient attention. However, the results in Section 4.6.2 quantitatively demonstrated the importance of carefully determining it. This has implications for both future research on local energy systems, and importantly, the work of practitioners such as local authorities or municipalities.

6.2.3 Literature review

The systematic literature review conducted in Chapter 3 firstly provides a useful synthesis of an emergent field of study for scholars seeking to move into this space, and secondly, having achieved this, points to a number of areas for further investigation. The key finding of the assessment was that examples following established transdisciplinary principles are limited, which highlights the need for exploration into collaborative/co-production approaches. This

was a gap which Chapter 5 sought to address. However, there remains a number of unanswered questions as discussed in Sections 5.5.4 & 6.1.1.

6.2.4 Exploring a co-production approach

A significant contribution of this thesis is the novelty of the co-production approach taken in Chapter 5. As demonstrated by the literature review in Chapter 3, there has been a very limited number of truly collaborative / co-production approaches to date. The adopted approach builds on suggestions for the bridging of participatory action research and energy system modelling tools (Geels et al., 2016), and provides critical reflections and learnings on the process to help guide future actions (Fazey et al., 2018). It demonstrates the need for further investigation into real-world transformation processes (Section 5.6), and lays bare the challenge of decarbonising the energy system within the next decade (Section 6.3.2). By providing critical reflections on the shortcomings and difficulties in Section 5.5.3 it offers important guidance for future researchers.

6.3 Recommendations

6.3.1 Developing a regional energy balance model for Ireland

Building on the dataset and methodology developed in Chapter 4, a regional model of the Irish energy system could be developed. The majority of the data is publicly available and published at the county-level, and currently, without more granular energy data, the unit energy consumption values would be the same across the country. It would thus be a relatively simple process to collate these sources and provide an open national repository of the energy balance in each county. Having it as a central system would be important to ensure a consistency in approach, which then facilitates coordination between the various sectors and actors. It could support energy infrastructure planning, the development of county-level climate action plans (Section 6.3.5) and those at the community level (Section 6.3.3).

The national database developed could be used to improve the delivery of energy master plans within the Sustainable Energy Authority of Ireland's Sustainable Energy Community Network by providing a means to coordinate energy planning across levels; from the national down to county level and then from county to community network. At present, there is no oversight on these plans which generally simply involve a republishing of publicly available data and offer nothing of value to the community group (Watson et al., 2019a), (McGookin et al., 2020a). The current national Climate Action Plan sets the target for 1,500 SECs by 2030, if each was

to develop an energy masterplan under the current grant system, it would result in public spending of between €25-30 million. With the coordination of baseline emission inventory through a central source, this money could be put to better use such as feasibility studies or energy audits, which would be far more useful assessments for the community groups (McGookin et al., 2020a).

6.3.2 An action-orientated research agenda

Returning to the central research question of Chapter 5 (Section 5.2), a key contribution of this thesis 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 (Amer et al., 2020), (Süsser et al., 2022).

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 (Geels et al., 2016), (Fazey et al., 2018), and more collaborative model design processes to ensure new developments remain relevant to policy and other actors (Amer et al., 2020), (McGookin et al., 2021c), (Süsser et al., 2022), discussed further in Section 6.3.3. This research serves to reiterate the need for greater involvement from the social sciences (Overland and Sovacool, 2020). 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 (Section 6.1.3).

Based on the experience of this thesis, at the community level, i.e. small regions such as the case study (Section 2.6), I am ultimately left to conclude that energy system modelling tools like LEAP are not the resource that is needed. What is needed is more ‘hands-on’ or action orientated approaches. Yes, the energy system model presented interesting findings (Section 5.5.2) and is important to identify mitigation measures, but the long-term planning exercise was never of interest to our community partners (Section 5.5.3). The baseline emissions

estimate (Chapter 4) was sufficient to point the way for them toward key sectors, and from there what they have regularly asked for is ways of monitoring emissions reductions associated with individual projects. It would be a better use of time and resource to develop energy system models at the level above community (local authority/municipality) and exploring ways of coordinating activities from there (Sections 6.3.3 & 6.3.5). Research at the community level should then focus on actively support decarbonisation efforts, while gathering learnings and reflections on transformation processes in order to support efforts elsewhere (Fazey et al., 2018). For example, the learning briefs co-produced with Dingle Peninsula 2030 partners, see further details in Appendix 3.A.1.

As noted in Section 5.5.3 and discussed further in Section 6.4.3, through this new research agenda, the slipping into roles better fulfilled by community development organisations should be approached with caution. However, is nonetheless an important way to give voice to those who are not often heard in national policy debates and point to weaknesses or blind spots in policy measures.

6.3.3 Getting the most from energy system models

As introduced in Section 6.3.1, while this thesis calls for a rethinking of research priorities, this is not to say we do away with energy system models entirely. These tools remain a useful means to understand emission pathways, as highlighted by: the gap between community ambition and renewable energy preferences, gap in national policy targets (Section 5.5.2), and key sources of emissions highlighted (Sections 4.6.2 & 5.4.3). Recognising that an in-depth involvement in the energy system model building process is unlikely to interest community groups (Section 6.3.1), the questions then becomes where would models be best placed. It is clear that more collaborative model design processes are needed to ensure new developments remain aligned with the needs of policy and other actors (Amer et al., 2020), (McGookin et al., 2021c), (Süsser et al., 2022).

The two key levels that emerge for consideration from this thesis is the local authority/municipal and national. Developing energy system models below the national level (Section 6.3.1), can support local actions (Sections 6.3.1 & 6.3.5), while also offering valuable learnings on emission reduction efforts (Section 5.5.2). The exact nature of these models will need to be worked out through collaboration with local authorities to ensure the outputs can support them in taking on an enhanced leadership role (Sections 6.3.2 & 6.3.5).

At the national level, as with the community, while public participation in the decision-making process is crucial, exactly how this is achieved remains unresolved (Section 6.1.1). Deliberative forums are needed to ensure fair and just climate policies (Section 5.5.1). There are ways of representing energy system models in interactive tools that could be used in such forums (Section 3.5.1.4), which would offer interesting insights into technology preferences. Ensuring that this doesn't omit broader considerations (Section 6.1.3) would require a carefully designed process, perhaps beginning with a much broader debate on desirable futures and ending with reflections on what is missing from the energy system modelling tool. Where energy system models are most useful, as illustrated by the results in Section 5.5.2, is answering important policy questions. This could be further strengthened by working closely with policymakers or energy experts to explore model inputs/outputs in more detail (Section 6.4.1). What becomes increasingly important then is the bridging of the various levels (Geels et al., 2016) and different stakeholder inputs (Section 6.4.4).

6.3.4 Building diverse research teams, and learning through constructive debate

A common thread through all of this thesis is the need for a diverse interdisciplinary research team (Section 6.1.4.3). Co-production / collaborative approaches should seek to build on existing expertise as opposed to becoming a separate field of investigation. Looking at the roles outlined above in Section 6.1.5, it is quite clear that a single individual will not be able to effectively perform all of them at the same time. Yes, it is important for technical experts to broaden their understanding of social science approaches in order to contribute to engagement processes and vice versa that social scientists have a basic understanding of the technical challenges, but emphasis should be placed on building diverse teams rather than individual researchers becoming 'Jack of all trades, master of none'.

In an ideal situation, the energy system modelling process might involve three central groups: technical experts focused solely on model building, social scientists who pose challenges to this group and transdisciplinary researchers sitting between the two groups. This would greatly help to strengthen the field and mitigate against some of the dangers such as a participatory process being seen to be more legitimate than conventional analysis just because it is participatory (Kindon et al., 2007), the quality of the technical analysis being diluted, or that bad practice may emerge as people not suited to participatory roles are pushed into them.

Teams constructed in this manner would facilitate forums whereby a diverse pool of knowledge can meet to discuss the respective merits of different approaches and investigate opportunities for bridging analytical methods. The social sciences would not only challenge who is participating in the debate (Stirling, 2008), but also ask important questions on the limitations of quantitative models and what they represent (Castree et al., 2014). Likewise, the modellers should ask questions of the participatory process and how it contributes to solutions. Having this debate in a constructive manner requires an openness, humility, and respect, as well as time to build a good working relationship. Professional settings such conferences or journal articles result in the debate being too antagonistic, or indeed not taking place at all as the differing perspectives never meet. It is of course acknowledged that there are organisational, institutional and funding challenges that prevent the creation of such diverse teams. However, the need for people to reach out and find creative ways of working together is nonetheless clear.

6.3.5 Aligning national climate targets and local delivery

As (Sperling et al., 2011) highlighted, local authorities have a key role to play both in the planning and implementation of decarbonisation solutions. There are two central roles for the local authority identified in this thesis. Firstly, developing an understanding of the energy system below the national level (Section 6.3.1), as is already facilitated through initiatives like the Covenant of Mayors, and has long been the case in countries such Sweden (Nilsson and Mårtensson, 2003) and Denmark (Möller, 2012). Secondly, improving the communication channels between policy and community needs in order to ensure fair and just climate action in a timely manner (Section 5.5.1).

The potential contribution of the Irish planning system to climate action was highlighted by the Chief Executive of the Office of the Planning Regulator during a recent special sitting of the Joint Oireachtas Committee on Climate Change (Cussen, 2021). At present, the placement of renewable energy projects is primarily developer-led, which can spark tensions during the planning application process (Section 2.2) and bears a financial cost for the developer. One means to address this weaknesses in the decision-making process would be a move to a plan-led deployment through: *“A national renewable energy roadmap with county-specific targets could provide the basis for designation of Sustainable Energy Zones by local authorities in their development plans”* (Ibid, p.3). A key benefit of this national *“spatially co-ordinated strategy”* would be to help build *“greater consensus on where and how to electrify our mobility, home heating and wider economic systems”* (Ibid, p.3).

Under Ireland's recent Climate Act 2021, local authorities have been given an enhanced leadership role. One interesting part of the new legislation is a requirement for each local authority to develop a Climate Action Plan addressing both mitigation and adaptation measures.

Firstly, this will require a regional energy system model as discussed in Section 6.3.1. A critical first step in the creation of the Climate Action Plans is to undertake a Baseline Emissions Inventory for the City or County. This sets a statutory requirement for local authorities to map out the GHG emissions within their administrative area. To date, local authorities have only dealt with their own direct emissions such as buildings, vehicles, etc., which would represent around just 1-2% of total emissions.

Secondly, it is an opportunity to explore more meaningful forms of public consultation and stakeholder engagement during the development of the plans. At present, rural areas in Ireland are suffering from a breakdown in communication between national, regional and local authorities and community needs (Sections 5.4.1). An essential component of delivering the rapid transformation needed within the next decade is thus the pursuit of more collaborative approaches. The creation of fora like the Belfast Climate Commission (Queen's University Belfast, 2021) and use of creative techniques such as those from the Imaging2050 project (Revez, 2021) offer exciting prospects.

6.4 Considerations for future research

6.4.1 Further opening of the energy system model building process

A gap identified during the systematic literature within Chapter 3 was to gather feedback on the model and results from participants (discussed in Section 3.6.3.1). The discussion of both model structure and parameters is important for a number of reasons. As noted in Section 2.5, models are inevitably shaped firstly by the views of the person building them and secondly, dominant social paradigms (Trutnevyte et al., 2016). In addition, there is the issue of uncertainty (Pye et al., 2018) and limitations of quantitative modelling techniques (McDowall and Geels, 2017).

Opening this discussion with a diverse range of stakeholders will provide interesting insights into the different perspectives and priorities, as well as prompting important questions on the use of models and their limitations. This importantly involves a more critical reflection on things that are often missing from energy system models such as demand-side measures or

deviation from the dominant economic growth paradigm (Pye et al., 2021), (Grubler et al., 2018). As (Castree et al., 2014, p. 766) note in their call for a broader debate on future pathways: “*Which facts are worth knowing, and which solutions worth pursuing, are partly a function of whose values (moral, spiritual, aesthetic) count and where the power to realize them lies*”.

New processes are needed to develop well-informed policy that can bridge the needs of both higher-level policy objectives and people’s everyday lives. As noted in Section 3.6.3.2, for energy system models and their results to contribute to these discussions new ways of opening up and interacting with the models are needed. A number of areas for further investigation include but are not limited to: further discussion of underlying assumptions with energy/environment ‘expert’ groups (as demonstrated by (Pye et al., 2018)), a broadening of the debate on what a desirable future is (as suggested by (Castree et al., 2014)), development of interactive tools that allow a wide audience to engage with the analysis (as in case of (Volken et al., 2018) and (Xexakis et al., 2020)), deliberative forums that can bring together a diverse range of opinions at the various policy levels, and exploring how energy system models move from plan to action.

6.4.2 Improving subnational energy demand and supply estimates

An important area of work as part of the development of the national database discussed in Section 6.3.1 would be to investigate ways of improving subnational estimates of energy demand and supply (as discussed Section 4.7). The top-down approach (Section 4.5.3.1) offers a useful starting point in the absence of the necessary local data but bottom-up representations are more robust and importantly, can more readily facilitate the monitoring of progress (Section 6.4.5). This would involve the building of more granular building and vehicle stock models, exploring available energy benchmarks, and then with access to recorded energy data a calibration of the estimate. Ireland currently does not have an energy benchmark standard and relies on the UK CIBSE guide. At a high-level this can be investigated by working with utility companies to get metered data for gas and electricity to compare against estimates determined for a region. At a more granular level, collaborations with residential, industry and commercial partners could look at actual building performance versus expectations.

Building on the regional energy balance database (Section 6.3.1), another interesting area of investigation is the mapping of energy demand and supply data through the use of GIS (Geographic Information System). This would be important for looking at the interaction

between climate mitigation and local authority planning, as well as better informed energy system planning by identifying clusters of energy demand and areas for renewable energy development. In addition, similar to the assessment in Section 5.4.1, it offers an opportunity to look at critical issues of equity and distributional justice such as: the overlap between statistical indicators of energy poverty and areas with high shares of low energy rated homes, distribution of public investment such as grant supports, or areas most at risk of poor air quality.

6.4.3 The evolving role of research

The advancement of transdisciplinary practice will require an honest and critical reflection from researchers to take learnings from failings as well as success stories. The difficulties discussed in Section 5.5.3 point to some of the barriers that need to be overcome. To address these along with other institutional barriers to the practice of transdisciplinary research, further investigation is warranted into the early career experience and development or support needs.

With regard funding and community engagement, a critical issue emerging from this investigation is the slipping into community development processes. Firstly, considering MaREI's broader involvement with *Corca Dhuibhne 2030*, the most significant contribution has likely been the hiring of a community engagement coordinator to work on emerging projects in agriculture and community energy. The funding of administration and coordination roles within community groups was a key gap identified by the previous work of (Watson et al., 2019a). This is thus a valuable contribution but raises questions about the use of research funding for community development purposes. Secondly, when it comes to the facilitator role, as noted in Section 5.5.3, when community development issues are being neglected, researchers seeking to work with community groups may find themselves filling roles that would be better served by local government or other public bodies.

Another element that emerged in this thesis was the question of co-authorship on outputs. In this case, the learning briefs were collaboratively produced but journal papers were not (outlined in Thesis outputs). With an increasing interest in these approaches, and the associated outputs (including journal papers) being agreed among diverse groups of stakeholders, the implications for research integrity and independence is an important area of discussion. How the evolving role of the honest researcher (Section 6.1.5), which poses a direct challenge to the traditional role of the scientist as a passive observer, changes the place of science in society remains to be seen.

6.4.4 Bridging action-orientated approaches and energy system modelling processes at the various levels

Reflecting on the recommendation in 6.3.1 and 6.3.3, it is important to note that it is not a case of either or when it comes to future research directions but how to strike a better balance between the two. An increasingly interesting area for investigation is how to facilitate feedback between the various policy levels (community, local and national) and how these interact with the different energy system modelling tools (Section 6.3.3).

It is suggested here that diverse research teams may be a good way forward to bridge participatory and technical approaches (Section 6.3.4), but it has by no means resolved the issue. The trade-off between a meaningful engagement and clear linkage to an energy system model discussed in Section 6.1.1, offers an interesting challenge for future investigation. When a participatory action research process is guided by a diverse group of stakeholders there is a chance it may bare no relevance to an energy system model if topics of interest are hard to integrate. Likewise, energy system models built by experts ‘behind closed doors’ risk being unrepresentative of the lived experience. However, exactly how the two work together at the various policy levels remains unclear.

6.4.5 Monitoring and evaluation

Monitoring and evaluation are important areas for investigation in a number of different contexts. Progress toward decarbonisation targets needs to be tracked overtime, as an ever-evolving super wicked problems, it is critical to regularly revisit measures and update plans as required. In addition, it is important for research to demonstrate impact and evaluate practices in order to draw out learnings for future research.

With regards tracking progress, there are some difficulties with the energy system models that are used to develop plans. Firstly, the issue of data availability is a significant constraint. This is an issue with both the initial estimate of CO₂ emissions (as discussed in Section 4.7) and measuring progress. In this case, the vast majority of data came from the Census of Ireland, which occurs every 5 years so updates are limited to that interval. Secondly, there is the issue of how the models are constructed. In the absence of locally available data for things like building size or details on the car stock, the method to determine energy-related CO₂ emissions relies on a downscaling of national statistics. The use of energy usage indicators like employees

or gross value added to determine the starting point subsequently makes it difficult to verify how the area is performing against decarbonisation goals.

From a research perspective, evaluation of projects is generally a funding requirement, but also importantly, can help the development of transdisciplinary research practices by drawing out learnings and failings to understand what works best. A key difficulty is posed by societal impacts that fall outside conventional metrics and cannot be easily determined, as well as the fact that the research intervention is so short relative to the long-term sustainability transition underway. Thus, further investigation into how sustainability initiatives diffuse through a community offers an interesting research and evaluation challenge. As the framework developed by (Pohl et al., 2021) shows, there are three distinct stages to a transdisciplinary research project: problem framing, analysis and exploring impact. There are some signs of progress emerging on the Dingle Peninsula (the central case study area for this thesis). However, it is only by revisiting it in ten- or twenty-years' time will we be able to clearly see the impact that the research and wider project had.

Another element of this as we move forward, is to revisit previous energy system plans. As (Trutnevyte et al., 2016) previously demonstrated by retrospectively reviewing UK energy policy, we can draw important learnings on the use of energy system models and what they represent. Firstly, it offers critical reflections on energy system models that are important to guide model developments (Section 6.3.3). Likewise, with regards policy, unpacking why previous targets set for 2020 were not achieved may provide learnings to help ensure future objectives do not suffer the same fate. On from this, the evaluation of deliberative forums and how the outputs from them are translated into energy system models and subsequent policy recommendations is crucial to understand how to strengthen the link between the various policy levels (as discussed in Section 6.4.1 & 6.4.4).

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Appendices

Chapter	Appendix	Content
3	Appendix 1.A	Search terms used for systematic review
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5	Appendix 2.A	Community engagement material and outputs
	Appendix 2.B	LEAP model documentation
6	Appendix 3	Contributions of the thesis to society and policy
	Appendix 3.A	Report on scientific communication and outreach
	Appendix 3.B	Example of ‘learning brief’ co-produced with Dingle Peninsula 2030 partners

Appendix 1.A Search terms used for systematic review

Scopus search with strings input for Title, Abstract and Keyword, results limited to English and conference proceedings excluded

Search strings			No. of results
'Climate change mitigation'	&	'Participatory'	259
'Energy modelling'	&	'Participatory'	130
'Energy system analysis'	&	'Participatory'	253
'Energy system modelling'	&	'Participatory'	86
'Energy system model'	&	'Participatory'	168
'Energy planning'	&	'Participatory'	386
'Energy scenarios'	&	'Participatory'	154
'Energy transition'	&	'Participatory'	177
'Engagement'	&	'Energy system modelling'	97
'Engagement'	&	'Energy planning'	389
'Engagement'	&	'Energy scenarios'	148
'Stakeholder participation'	&	'Energy system modelling'	25
'Stakeholder participation'	&	'Energy planning'	207
'Stakeholder participation'	&	'Energy scenarios'	63
'Stakeholder engagement'	&	'Energy system modelling'	23
'Stakeholder engagement'	&	'Energy planning'	156
'Stakeholder engagement'	&	'Energy scenarios'	56
'Stakeholder dialogue'	&	'Energy system modelling'	9
'Stakeholder dialogue'	&	'Energy planning'	48
'Stakeholder dialogue'	&	'Energy scenarios'	19
'Transdisciplinary'	&	'Energy system modelling'	20
'Transdisciplinary'	&	'Energy planning'	45
'Transdisciplinary'	&	'Energy scenarios'	24
			2,942

Appendix 1.B Analysis tables used to summarize the papers reviewed

Table 1.B.1. List of papers reviewed in this study and their foci.

Ref.	Scale			Energy System Coverage							
	Sub-national		National	Whole System	Mode			Sector / Technology			
	City / Town	Regional			Electricity	Heating	Transport	Housing	Solar PV	Wind	Bioenergy
(Giannouli et al., 2018)		x		x							
(Alvial-Palavicino et al., 2011)	x				x						
(Bertsch and Fichtner, 2016)			x		x						
(Busch, 2017)		x									x
(Schmid and Knopf, 2012)			x	x							
(Flacke and De Boer, 2017)	x			x							
(Höltinger et al., 2016)			x							x	
(Nabielek et al., 2018)		x			x	x					
(Ernst et al., 2018)			x	x							
(Jeong, 2018)		x									x
(Uwasu et al., 2020)	x			x							

(Soria-Lara and Banister, 2018)		x					x				
(McKenna et al., 2018)		x		x							
(Krzywoszynska et al., 2016)	x			x							
(Bessette et al., 2014)		x			x						
(Demski et al., 2017)			x	x							
(Steinberger et al., 2020)			x		x						
(Salerno et al., 2010b)		x									x
(Dubinsky et al., 2019)		x							x		x
(Zivkovic et al., 2016)	x						x				
(Schmid et al., 2017)			x		x						
(Mayer et al., 2014)		x			x						
(Simoos et al., 2019)	x			x							
(Macmillan et al., 2016)			x						x		
(den Herder et al., 2017)		x									x
(Venturini et al., 2019)			x				x				
(Zelt et al., 2019)			x		x						

(Fortes et al., 2015)			x	x							
(Sharmina, 2017)			x	x							
(Vargas et al., 2018)		x			x						
(AlSabbagh et al., 2017)			x				x				
(Xexakis et al., 2020)			x		x						
(Schinko et al., 2019)			x	x							
(Marinakos et al., 2017a)	x			x							
(Madlener et al., 2007)			x		x	x					
(Eker et al., 2018)			x					x			
(Volken et al., 2018)			x		x						
(McDowall, 2012)			x	x							
(Robertson et al., 2017)			x	x							
(Terrados et al., 2007)		x			x						
(Mathy et al., 2015)			x	x							
(Bernardo and D'Alessandro, 2019)	x			x							
(Chapman and Pambudi, 2018)			x		x						

(Trutnevyte et al., 2011)	x				x	x					
(Kowalski et al., 2009)	x		x	x							
(McDowall and Eames, 2007)			x	x							
(Schmuck, 2012)	x										x
(Düspohl et al., 2012)		x		x							
(Atwell et al., 2011)		x									x
(Foran et al., 2016)		x						x			
(Vaidya and Mayer, 2016)		x									x
(Thomas et al., 2018)		x		x							
(Olabisi et al., 2010)		x		x							

Notes

1. “Participatory system dynamics modelling for housing, energy and wellbeing interactions” (Eker et al., 2018) details on participants taken from “Integrating GMB and games in the built environment” (Carnohan et al., 2016)
2. “Reconciling qualitative storylines and quantitative descriptions: an iterative approach” (Robertson et al., 2017) modelling tool used taken from “Modelling generation and infrastructure requirements for transition pathways” (Barnacle et al., 2013)
3. “Societal implications of sustainable energy action plans: from energy modelling to stakeholder learning” (Bernardo and D’Alessandro, 2019) software used for analysis taken from “Strategic Energy Planning of Residential Buildings in a Smart City: A System Dynamics Approach” (Caponio et al., 2015)
4. “Energy, Forest, and Indoor Air Pollution Models for Sagarmatha National Park and Buffer Zone, Nepal” (Salerno et al., 2010b) software used for analysis taken from “Experience With a Hard and Soft Participatory Modelling Framework for Social-ecological System Management in Mount Everest (Nepal) and K2 (Pakistan) Protected Areas” (Salerno et al., 2010a)

Table 1.B.2. Summary of the stakeholders involved with subnational energy system studies.

Ref	State							Market					Community					participants				
	local			national				energy industry	tourism	agriculture / forestry	construction	finance / bank	unspecified	private individuals / citizens	formal group							
	planning agency	government	energy / environment	labour agencies	researchers / academia	government	health / education								environmental / energy	farmer's association	energy co-op / association		environmental association	religious institution	development organisation	unspecified
(Giannouli et al., 2018)		x		x	x					x	x	x					x		x			17
(Alvial-Palavicino et al., 2011)														x		x						100
(Busch, 2017)	x															x		x				100
(Flacke and De Boer, 2017)		x												x		x						35

(Nabielek et al., 2018)		x			x				x					x					30
(Jeong, 2018)	x	x			x				x										105
(Uwasu et al., 2020)													x						446
(Soria-Lara and Banister, 2018)					x	x			x										NA
(McKenna et al., 2018)		x	x							x									19
(Krzywoszynska et al., 2016)		x										x	x				x	x	15
(Bessette et al., 2014)													x						182
(Salerno et al., 2010b)					x			x		x							x	x	NA
(Dubinsky et al., 2019)		x						x						x			x		NA

(Zivkovic et al., 2016)	x	x	x	x	x				x						x						NA	
(Mayer et al., 2014)															x							69
(Simoes et al., 2019)	x	x			x				x						x							NA
(den Herder et al., 2017)					x		x	x	x	x					x							40
(Vargas et al., 2018)										x					x							NA
(Marinakis et al., 2017a)	x	x							x						x							NA
(Terrados et al., 2007)									x	x	x				x						x	500
(Bernardo and D'Alessandro, 2019)										x												NA
(Trutnevte et al., 2011)			x			x									x	x	x				x	29

(Kowalski et al., 2009)		x			x					x			x								NA
(Schmuck, 2012)		x									x			x							NA
(Düspohl et al., 2012)	x		x		x					x			x		x						NA
(Atwell et al., 2011)								x			x			x	x	x					16
(Foran et al., 2016)		x														x			x		15
(Vaidya and Mayer, 2016)		x			x	x			x		x			x		x					NA
(Thomas et al., 2018)														x							83
(Olabisi et al., 2010)	x	x				x	x	x			x						x				NA

(Hölting er et al., 2016)		x		x		x		x					x								28
(Ernst et al., 2018)				x	x				x	x										x	NA
(Demski et al., 2017)													x								1800
(Steinbe rger et al., 2020)													x								44
(Schmid et al., 2017)				x						x					x					x	26
(Macmil lan et al., 2016)		x			x	x			x							x				x	50

Table1.B.4. Table of the qualitative and quantitative methods used in the studies reviewed.

		Qualitative Analysis							Quantitative Analysis						
		Eliciting Preferences			Visioning / Mapping				Assessments	Energy System Models					
		Individual		Group						multi-criteria decision analysis	sensitivity analysis	resource assessment	system dynamics modelling	simulation tool	optimisation tool
		survey/questionnaire	semi - structured interview	dialogue / deliberation	interactive display / serious game	scenario generation / backcasting	SWOT analysis	storytelling / visioning	cognitive mapping						
Subnational	(Giannoli et al., 2018)						x		x						
	(Alvial-Palaviccino et al., 2011)		x	x					x						
	(Busch, 2017)					x				x		x			
	(Flacke and De Boer, 2017)			x	x										
	(Nabielek et al., 2018)				x							x			
	(Jeong, 2018)	x									x		x		

(Uwasu et al., 2020)	x		x	x	x		x	x						
(Soria-Lara and Banister, 2018)	x	x			x									
(McKenna et al., 2018)	x							x	x	x				x
(Krzywoszynska et al., 2016)					x							x		
(Salerno et al., 2010b)						x		x					x	
(Dubinsky et al., 2019)		x	x		x							x		
(Zivkovic et al., 2016)						x	x	x						x
(Mayer et al., 2014)	x				x									
(Simoes et al., 2019)			x			x				x				x
(den Herder et al., 2017)	x									x				

(Vargas et al., 2018)	x	x									x			
(Marinkis et al., 2017a)	x								x	x				
(Terrados et al., 2007)						x					x			
(Bernardo and D'Alessandro, 2019)						x			x				x	
(Trutnev et al., 2011)						x				x		x		
(Kowalski et al., 2009)						x				x		x		
(Schmuck, 2012)				x						x		x		
(Düspohl et al., 2012)			x			x				x				
(Atwell et al., 2011)	x					x								
(Foran et al., 2016)			x			x								
(Vaidya and			x								x		x	

	Mayer, 2016)														
	(Thomas et al., 2018)				x										
	(Olabisi et al., 2010)					x		x					x		
National	(Bertsch and Fichtner , 2016)	x									x				x
	(Schmid and Knopf, 2012)	x						x							x
	(Hölting er et al., 2016)	x				x						x			
	(Ernst et al., 2018)	x				x		x							
	(Demski et al., 2017)					x									
	(Steinbe rger et al., 2020)	x		x	x										
	(Schmid et al., 2017)		x				x								

(Macmillan et al., 2016)		x					x	x					
(Venturini et al., 2019)					x								x
(Zelt et al., 2019)	x				x				x			x	
(Fortes et al., 2015)					x								x
(Sharmina, 2017)		x			x								
(AlSabbagh et al., 2017)		x			x							x	
(Xexakis et al., 2020)	x		x	x									
(Schinko et al., 2019)					x						x		
(Madlener et al., 2007)		x			x				x				
(Eker et al., 2018)		x						x				x	

(Volken et al., 2018)	x			x										
(McDowall, 2012)		x			x									x
(Robertson et al., 2017)		x			x						x			
(Mathy et al., 2015)	x				x								x	
(Chapman and Pambudi, 2018)	x													x
(Kowalski et al., 2009)		x			x					x				
(McDowall and Eames, 2007)		x			x					x				

Appendix 2.A Community engagement material and outputs

Table 2.A.1. Local and national partners the research team is actively collaborating with as part of ‘Corca Dhuibhne 2030’

Stakeholder Groups	Description	Role in the project	Input into energy scenarios
North East West Kerry Development (NEWKD)	Non-profit community development organisation in the region	Providing link to existing community networks	Co-organising the community meetings held and ongoing discussion of energy system modelling scenarios/results
Dingle Creativity & Innovation Hub (Mol Téic)	Non-profit primarily focused on enterprise development in the region	Establishing the Sustainable Energy Community group and a number of other sustainability initiatives including Anaerobic Digestion feasibility study, farm ambassador programme	Co-organising the re-imagine Dingle Peninsula workshop, and ongoing discussion of energy system modelling scenarios/results
ESB Networks	National distribution system operator	Running a trial on the electrification of heat/transport in part of the region	High-level ambition for the electrification of heating and transport
Dingle Peninsula Sustainable Energy Community	Voluntary group formed out of Mol Téic to access grant support for energy planning and building	Developed an energy masterplan, providing an estimate of energy related CO ₂ emissions in the region	Collaboratively prepared a previous estimate of energy related CO ₂ emission in the region (McGookin et al., 2020b)

	energy improvements		
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Student workshop

Questions posed

- What do you like about being from Dingle?
- Anything you would like to change about Dingle in the short/long term?
- Please write a paragraph describing the Dingle you would like to see in the future.
Think about questions like; How has the community developed? What jobs are people doing? How do people get around? What are the houses like? How has the landscape changed?
- Do you have any further comments / suggestions on the initiatives developing on the Peninsula? Is there anything you think the Hub or ESB Networks should be doing or could be doing better? Or any other stakeholders you think should be involved?
- Do you have any further comments / suggestions on the proposed research? Is there anything you think we should be doing or could be doing better?

Summary of findings

Theme 1: Dingle is a small, tightly knit community	Key questions arising
<p>Small town culture</p> <ul style="list-style-type: none"> • Everybody knows each other • It's a very safe place to live • It's a very diverse community, plenty of well-integrated blow-ins • There is a good sense of community • People of Dingle are hardworking, proud of the area and committed to promoting / preserving it • It thrives because of; 	<p>How can Dingle protect this strong sense of community into the future?</p> <ul style="list-style-type: none"> ➤ Handling the integration of more people <i>“Increasing number of blow-ins may change the character of the community”</i> ➤ Planning infrastructure / development appropriately

<p><i>“The hardworking nature and innate want of people who live in Dingle to make Dingle a better place”</i></p> <p>Vibrant area</p> <ul style="list-style-type: none"> • Great tourist destination • Plenty of summer job opportunities <i>“For a town of its size it has many opportunities other towns don’t have due to the tourism industry”</i> • Many festivals; film, food, arts music – always something happening <i>“As a young adult, there is loads of reasons to come home every weekend, e.g. food festival, Other Voices, etc”</i> 	
<p>Theme 2: The Dingle peninsula is a beautiful landscape</p>	<p>Key questions arising</p>
<p>Place of natural beauty</p> <ul style="list-style-type: none"> • Great scenery • Very natural place <i>“Dingle is still more in touch with a traditional way of living”</i> <p>Protecting the landscape</p> <ul style="list-style-type: none"> • Increasing tourism shouldn’t threaten landscape <i>“I’d like the landscape to stay the same, as natural as possible”</i> <i>“Landscape untouched. Beaches, wildlife being protected.”</i> 	<p>How can Dingle ensure that increasing number of tourist and demand for infrastructure / development doesn’t impact on the landscape?</p>

<ul style="list-style-type: none"> • Increase in littering if tourism keeps expanding 	
<p>Theme 3: Lack of Opportunities for Youth</p>	<p>Key questions arising</p>
<p>The “brain drain”</p> <ul style="list-style-type: none"> • Limited opportunity outside of hospitality and agriculture • Need for higher scale job opportunities <p><i>“steer our reliability away from tourism”</i></p> <p><i>“I would like to see Dingle as a place that people who grew up in Dingle could come back to and use their qualification.”</i></p> <ul style="list-style-type: none"> • Continued unsustainable growth in the tourism sector makes the area increasing less attractive to native people seeking to work outside of hospitality <p>Lack of access to Wi-Fi</p> <ul style="list-style-type: none"> • There needs to be a reliable internet connection • More modern facilities like the Hub available <p><i>“love to see more work spaces like the Dingle Hub from which people can pursue international careers”</i></p> <p>Lack of long-term rentals</p>	<p>How can the Dingle Creativity and Innovation Hub (expand it’s services to offer D young people the chance to work remotely?</p> <ul style="list-style-type: none"> ➤ Promoting the notion of working from home ➤ Drawing in interested companies ➤ Expanding on Wi-Fi access

<ul style="list-style-type: none"> • Limited amount of long-term rentals available • Young people choosing to stay in Dingle can't find anywhere to live <i>"There are far too many short-term houses being let, we need long term letting."</i> 	
Theme 4: Planning / Infrastructure	Key questions arising
<p>Remoteness</p> <ul style="list-style-type: none"> ➤ Small isolated towns scattered around the peninsula at risk ➤ Lack of facilities for young people. <i>"not a lot of things for young people (secondary school students) to do outside of school"</i> <p>Essentially no public transport, heavy reliance on car</p> <ul style="list-style-type: none"> ➤ Need for better planned infrastructure ➤ Traffic during tourism season a problem <i>"like to see Dingle as a place that is free of traffic congestion"</i> <i>"No more widening of roads"</i> ➤ With more transport options <i>"The infrastructure is as good as it should be, the only addition I could see is bicycle lanes"</i> <i>"a smart system of transport for the elderly"</i> <p>Room for improvement</p>	<p>Could the future developments be better planned, considering the concerns of locals?</p>

<ul style="list-style-type: none">➤ Small farmers, eager to explore new sources of income➤ Very dispersed housing/buildings, leaving plenty of room for the development of new industry➤ However, some also highlighted a fear of developers; <i>“who solely see Dingle as an opportunity to make money”</i>➤ Moreover, noted the need to protect less developed areas in the interest of protecting the nature beauty. <i>“Not allowing planning permission outside of towns, ruining the landscape”</i>	
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Community meetings

Agendas

Table 2.A.2. First round of meetings, November 2019

Time	Activity
00:00	Welcome / Purpose of the Meeting and the Overall Project
00:05	Presentation of Demographic and Socio-Economic Profile
00:20	Feedback with Q&A (on profile)
00:30	Presentation of Key Environmental Facts about the Dingle Peninsula
00:40	Feedback with Q&A (on environment and energy)
00:50	Break
01:00	Community Planning
	<p>Participants will work in buzz groups dealing with the following themes:</p> <ul style="list-style-type: none"> i Economic Development ii Community iii Wellbeing iv Environment and Energy <p>They will discuss and assess – <u>with specific reference to their chosen theme</u>:</p> <ul style="list-style-type: none"> i In this community, what are we doing well? ii What are the main issues locally (in respect of this theme)? iii What needs to be done? / What actions need to be taken? iv Who needs to take those actions? When? How best?
01:30	Feedback from the groups
01:50	Next Steps
02:00	Close of meeting

Table 2.A.3. Second round of meetings, February 2020

Time	Activity
0:00	Welcome
0:05	Recap on the Demographic and Socio-Economic Profile - to conclude with a one-slide overview on 'the main features of this community'
00:10	Recap on the energy presentation – bespoke for each community

00:15	Presentation of the Vibrancy Survey Results – to conclude with a one-slide overview on ‘the main implications for this community’
0:25	Feedback on the roundtable discussions (that took place at the November / December meetings) – the development priorities for each community
0:35	Q & A
0:45	Break
0:55	A Vision for the Community and the Peninsula – visioning exercise
	<p>Buzz Groups – tables by theme:</p> <ol style="list-style-type: none"> 1. An Ghaeilge (Irish) – language and culture 2. Housing 3. Environment and Energy 4. Economic Development, Agriculture, Fisheries and Tourism 5. Children, Youth and Families 6. Infrastructure, Amenities and Connectivity 7. Health, Wellbeing and Social Services <p>Discussion Questions:</p> <ol style="list-style-type: none"> a. Where is there potential? / What are the opportunities? b. List five (approx.) projects (under this theme) that would benefit this community. c. What would be main benefits / outcomes be? d. What can we, as a community, do to deliver these projects?
1:40	Feedback from each table
2:00	Open Forum – discussion on the next steps
2:15	Close of meeting

Summary of findings

As noted in the text, the notes recorded during the community meetings have been published online.

- First round of meetings, November 2019 (Ó Caoimh and McGookin, 2021b)
- Second round of meetings, February 2020 (Ó Caoimh and McGookin, 2021a)

Along with a detailed report of the findings from the demographic and socio-economic profile (Ó Caoimh and McGookin, 2021c), and a learning brief reflecting on the evidence-based community planning process (McGookin et al., 2021e).

Renewable energy perspectives

Table A.2.4. Local perceptions of renewable energy options.

On-shore wind	<ul style="list-style-type: none"> • The potential for large-scale onshore wind was ruled out due to concerns that such an installation even if comprising only 1 to 3 large wind turbines would damage the region’s reputation for a beautiful natural landscape and may subsequently impact vital tourism revenue • There was a lot of interest in micro wind turbines, although these show limited viability in urban settings, an isolated area such as the case study region has sites suitable for pole-mounted horizontal axis turbines (Tummala et al., 2016)
Solar PV	Keen interest in rooftop solar PV on households, public buildings, farm sheds, etc.
Hydro	Small-scale hydro energy was also seen as having great potential with a number of identified sites around the area. However, these developments have been stalled due to difficulty in securing connection to the electricity grid and a refusal from the local planning authority to allow such installations to impact arable agricultural land
Bioenergy	There is ongoing investigation into the potential for anaerobic digestion in the region, with an initial feasibility study suggesting a potential available resource (grass, food waste and animal by-products) of 305 GWh (XD Consulting, 2020), which would be equivalent to the total energy demand. However, there are significant difficulties in matching the biogas produced with suitable energy demands. Furthermore, due to concerns raised over the plant size and associated traffic, the group have opted to develop a significantly smaller unit producing around 10 GWh per annum
Ocean energy	Offshore renewables such as tidal or ocean energy were widely seen as a solution as these would be ‘hidden’ from view. However, these technologies were not considered to be at mature enough stages of development to be considered for the period 2020-2030, which is the focus of this analysis.

Appendix 2.B LEAP model documentation

A copy of the Dingle Peninsula LEAP energy system model and associated data are available for download from the MaREI Centre, Energy Policy & Modelling Group GitHub repository - https://github.com/MaREI-EPMG/LEAP_Dingle_Peninsula

LEAP Model Examples

No. of houses	2010	2015	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	26	47	133	151	169	187	205	223	241	259	277	295	313	331
B	518	580	588	717	845	974	1,102	1,231	1,359	1,488	1,616	1,745	1,873	2,002
C	1,520	1,526	1,526	1,768	1,724	1,382	1,334	1,286	1,238	1,190	1,142	1,094	1,046	998
D	1,108	1,108	1,108	1,283	1,250	1,003	968	933	899	864	829	794	759	724
E	582	582	582	564	545	527	509	491	472	454	436	418	399	381
F	277	277	277	268	260	251	242	233	225	216	207	198	190	181
G	592	592	592	573	555	536	517	499	480	462	443	424	406	387
SUBTOTAL	4,623	4,712	4,806	5,324	5,348	4,860	4,878	4,896	4,914	4,932	4,950	4,968	4,986	5,004
Apartments	137	121	121	121	121	121	121	121	121	121	121	121	121	121
Holiday homes	1,876	1,924	1,989	1,502	1,511	2,028	2,041	2,054	2,067	2,080	2,093	2,106	2,119	2,132
Total	6636	6757	6916	6947	6980	7009	7040	7071	7102	7133	7164	7195	7226	7257

No. of homes: Activity Level (Households)																					
Branch	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A rated	26	30	34	39	43	47	69	90	112	133	151	169	187	205	223	241	259	277	295	313	331
B rated	518	530	543	555	568	580	582	584	586	588	594	600	606	612	618	624	630	636	642	648	654
C rated	1,520	1,521	1,522	1,524	1,525	1,526	1,526	1,526	1,526	1,526	1,812	1,810	1,514	1,510	1,506	1,502	1,498	1,494	1,490	1,486	1,482
D rated	1,108	1,108	1,108	1,108	1,108	1,108	1,108	1,108	1,108	1,108	1,316	1,316	1,102	1,100	1,098	1,096	1,094	1,092	1,090	1,088	1,086

Figure 2.B.1. Example of Excel data linked to LEAP key assumptions folder, showing the number of houses by building energy rating, with adjustments for COVID impact (blue text).

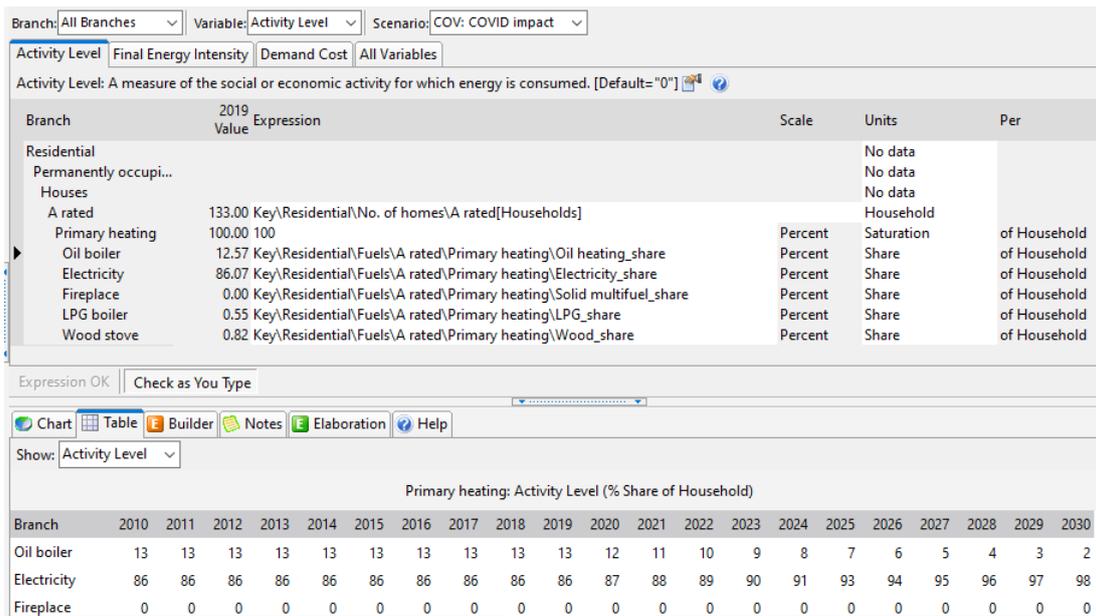


Figure 2.B.2. Example of activity level in LEAP demand folder, showing number of A rated homes and % share of different fuel source in primary heating.

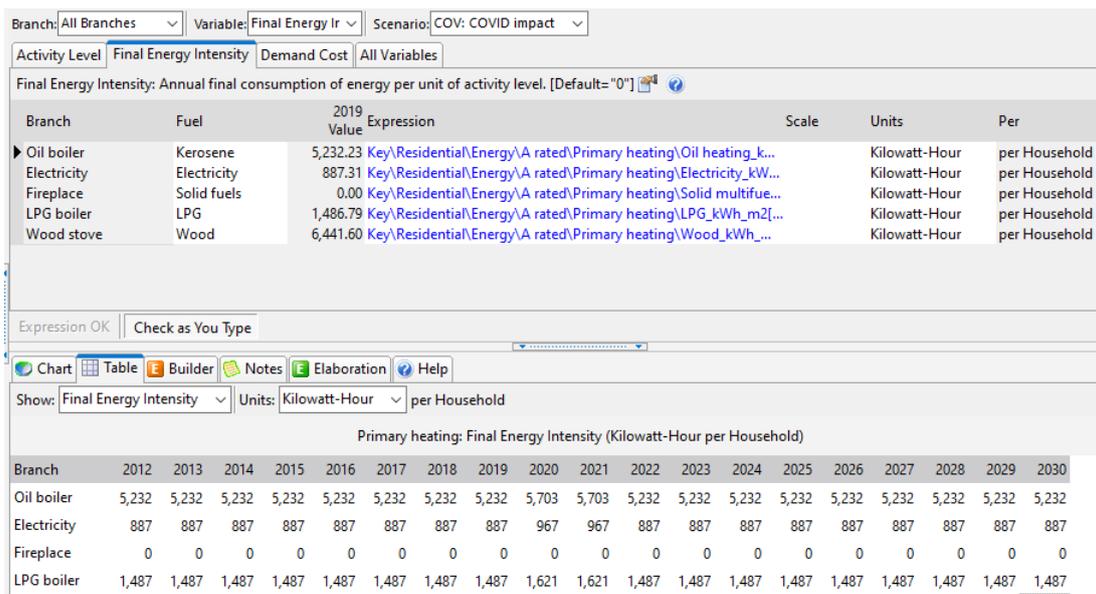


Figure 2.B.3. Example of final energy intensity in LEAP demand folder, calculation of energy demand (kWh/household) by fuel source in primary heating for A rated homes.

Key Assumptions

Table 2.B.1 - Historical population change between 2002-2016

	Dingle Peninsula	Co. Kerry	Ireland
Population 2002	11,679	132,527	3,917,203
Population 2016	12,508	147,707	4,761,865

Change 2002-2016	829	15,180	844,662
Growth (%)	7.1%	11.5%	21.6%
Yearly average growth (%)	0.51%	0.82%	1.54%

Table 2.B.2 - Population, homes and cars for the historical years (2002, 2006, 2011, 2016, 2019) and scenario end year (2030)

	Historical years				Scenarios	
	2002	2006	2011	2016	REF	BFB
					2030	2030
Population	11,679	12,268	12,549	12,508	13,489	14,675
Homes	4,337	4,669	4,623	4,712	5,079	5,523
People / household	2.69	2.63	2.71	2.65	2.66	2.66
Cars	5,392	6,251	6,696	6,815	7,429	8,179
Cars / household	1.24	1.34	1.45	1.45	1.46	1.48

Data sources

The process to acquire data and filter it for the case study region was previously outlined in McGookin et al. (McGookin et al., 2021a). Table 1 provides an overview of the model variables by sector and the relevant source.

Table 2.B.3. Energy usage indicators and other key data sources by sector

Sector	Variables	Unit	Source
All	Population, number of homes, cars, and other Census data (McGookin et al., 2021a)	NA	Census of Ireland 2016, Small Area Population Statistics (Central Statistics Office, 2016a)
	Energy demand and supply by sector	toe	Sustainable Energy Authority of Ireland, National Energy Balance 1990-2018 (Sustainable Energy Authority of Ireland, 2021c)
	Gross value added by sector	€ million	CSO County Income and Regional GDP 2016 (Central Statistics Office, 2016d)
	Employees by sector	Employees	CSO Business Demography (Central Statistics Office, 2016f)

Industry & Services	kWh/m ² for energy service demands (electricity, heating, etc.) and associated fuel share by business type	Multiple	Sustainable Energy Authority of Ireland, National Building Energy Rating Register (Sustainable Energy Authority of Ireland, 2020a)
Industry & Services	Floor area by business type in the case study region	m ²	Consultant's building survey prepared for Dingle Peninsula Sustainable Energy Community (McGookin et al., 2020b)
Agriculture	Hectares of land	ha	Census of Agriculture (Central Statistics Office, 2010)
Fishing	Weight of fish landed	tonne	CSO Fish Landings 2007-2018 (Central Statistics Office, 2018)
Residential	By energy rating – the no. of houses, average size, and fuel shares for primary / secondary / water heating	Multiple	Sustainable Energy Authority of Ireland, National Building Energy Rating Research Tool (Sustainable Energy Authority of Ireland, 2021b)
Residential	Number of new houses built 2011-2019	Homes	CSO, New Dwelling Completions (Central Statistics Office, 2020)
Residential	Breakdown of energy demand by use in households	NA	SEAI, Energy in the Residential Sector 2018 (Sustainable Energy Authority of Ireland, 2018b)
Transport	No. of public service and freight vehicles	NA	Irish Bulletin of Vehicle and Driver Statistics 2016 (Department of Transport, 2016)
	Road traffic volumes during pandemic lockdowns	%	Traffic Count Data for N86 Between Dingle and Annascaul, Emlagh, Co. Kerry (Transport Infrastructure Ireland, 2022)

Transport – private car	Km/year and kWh/km by engine size	Multiple	Irish Car Stock Model 2.0 (O’Riordan et al., 2021)
Transport - Road freight & Private car	Distance travelled	Km	CSO Transport Omnibus 2016; Road traffic volumes (Central Statistics Office, 2016h)
Transport - Road freight	Weight carried	Tonne km	CSO Transport Omnibus 2016; Road freight transport (Central Statistics Office, 2016g)

Appendix 3.A Contributions of the thesis to society and policy

3.A.1 Societal

Supporting local action on the Dingle Peninsula

Central to this thesis has been the participatory action research approach. As a member of the *Corca Dhuibhne 2030* partnership I have offered ongoing advice and support to our local partners, as well as coordinating a number of events with them. There have been two key contributions in particular: support for the local energy system planning and delivering a series of community meetings to produce an evidence-based strategy for the area.

During the course of the technical analysis carried out in Chapter 4, I was a prominent member of the Dingle Peninsula Sustainable Energy Community steering committee. This group was setup to coordinate the creation of an ‘Energy Masterplan’, covering baseline CO₂ emissions and decarbonisation options. The analysis that was published in a peer-reviewed paper, also informed the co-production of a short report with the steering committee (McGookin et al., 2021b), (McGookin et al., 2020b). Having been the lead author on the report, I subsequently presented the key findings at a number of local events and condensed the information into a brief with accompanying template for the ‘Climate Hack’ with secondary schools in the area.

The analysis of current energy-related CO₂ emissions provided a basis for the LEAP model developed. Central to this process was the pursuit of a co-production approach. This meant the research was designed with our local partners, and thus was embedded within initiatives taking place in the area. Our (national) research centre (MaREI), based out of UCC, provided a small contribution (€3,000) of matched funding that supported the local community development company in securing a larger grant (€27,000) to conduct a demographic and socio-economic assessment of the area that would inform a strategic plan. Through my involvement in the process the remit was expanded to include climate and energy issues. As outlined in Sections 5.4.1 & 5.4.2, this importantly placed the discussion on energy system futures within the broader societal context, as well as helping real-world projects emerge. The work informed a successful application for Dingle to be Ireland’s representative in the EU ‘Smart Rural Areas in the 21st Century’ network (North East West Kerry Development, 2021).

Sharing learnings from Corca Dhuibhne 2030

The creation of learning briefs with partners from the *Corca Dhuibhne 2030* project is an important means of gathering reflections and evaluating activities, but also importantly for disseminating the learnings. They are very short documents (generally 4 – 6 pages) highlighting key lessons learnt and recommendations from a particular event (e.g. LED bulb swap, climate hacks with schools) or process (e.g. preparing an energy masterplan or evidence-based community planning). Although the writing is led by researchers, it is done through a collaborative process initiated by a workshop (or series of workshops) on the topic and then iterative feedback on the document. These have informed policy recommendations (Appendix 3.A.2) but also importantly offer insights for practice. I have shared practical learnings with a number of community groups that reached out to me directly and am also supporting the delivery of a sustainable community training initiative being run by the SECAD partnership (SECAD Partnership).

Scientific communication and outreach

I have been a regular advocate for science and engineering. Being a regular volunteer for outreach events hosted by the research centre, as well as coordinating a number of events with partners from the Dingle Peninsula. In addition, I was a co-teacher for the STEAM Education ‘Engineering in a Box’ and ‘Math in a Box’. These courses are designed to get primary school students interested in key subjects through a series of fun, interactive exercises. During Engineers Week 2020, I won the “*I’m an engineer, get me out of here!*” competition, which involves a series of sessions with primary schools students who pose questions on what it’s like to be an engineer and then vote for their favourite representative. The extent of my contributions is outlined in Appendix 3.B.

3.A.2 Policy

Membership of the Project Advisory Group for the development of Ministerial Guidelines on Local Authority Climate Action Plan

Under Ireland’s recent Climate Action and Low Carbon Development (Amendment) Act 2021, the role of the local authority was greatly expanded (Department of the Environment, 2021a). One of the key elements was the introduction of a requirement for local authorities to prepare Climate Action Plans covering both mitigation and adaptation. Within this, the remit of baseline CO₂ emission profiles developed by the local authorities was extended from their

direct responsibilities (such as public buildings, etc.) to jurisdiction wide. I have been invited to advise on the climate mitigation planning element of the Ministerial Guidelines under preparation, sharing my experience both as a member of *Corca Dhuibhne 2030*, and in particular the development of the framework in Chapter 4. This investigation into approaches for determining subnational energy demand/supply uncovered a number of gaps in the data currently available in Ireland and issues with commonly used methodologies throughout national/international examples. These are important considerations to inform the tiered approach being adopted that will allow local authorities to begin at a very basic level and then work toward more granular and robust representations of the CO₂ emissions in their area.

Translating research insights into policy recommendations

The learning briefs prepared with *Corca Dhuibhne 2030* partners supported the MaREI submission on Citizen Engagement and Dialogue to the Oireachtas Committee Pre-Legislative Scrutiny of the Climate Action and Low Carbon Development (Amendment) Bill 2020 (Brian Ó Gallachóir et al., 2020).

Improving the math curriculum with the Department of Education

Based on the template that was developed to deliver ‘Climate Hacks’ with secondary school students on the Dingle Peninsula (McGookin C., 2020), a student elsewhere performed an assessment of the energy related-CO₂ emissions in their area as part of their continuous based assessment for junior cycle Math. This prompted discussion with the Department of Education, which led to a proposal to create an online portal (linked to that discussed in Section 6.3.1) that would facilitate the integration of these calculations and data handling into the junior cycle Math curriculum.

Appendix 3.B Report on scientific communication and outreach

Table 3.B.1. Overview of outreach and education activities.

Activity	Description	Date	Hours
Engineering / Maths in a Box	Engineering and maths programmes for primary school fifth / sixth classes, taught through 1hr lessons. I have been responsible for the delivery of lessons in six different schools over the last	March 2018 – December 2019	45

	two years. The goal is to introduce basic engineering/maths principles using fun/interactive exercises.		
Tech week event	Represented MaREI Centre at a family day hosted by the Dingle Creativity and Innovation Hub. We have a box of tricks to catch kids / parents such as electronic kits, model wind turbines and a miniature anaerobic digester.	April 2018	6
Ploughing championships	Manned the MaREI Centre stand in the SFI tent, as described above.	October 2018	8
Climate change in a bottle	Helped prepare a ‘climate change in a bottle’ demonstration and represented the Environmental Research Institute for a full day during Science Week 2018	November 2018	6
LED bulb swap	Assisted Dingle Creativity and Innovation Hub in the organising of a LED blub swap, giving people new LED bulbs in exchange for old incandescent and starting a conversation about energy in the home.	April 2019	3
Climate hack	Organised an event as part of Science Week 2019 in three secondary schools across the Dingle Peninsula. It involved giving the TY students information on the area’s energy usage and asking them to develop ideas / solutions for reducing CO2 emissions.	November 2019	9
			77

Reflection on skills acquired through outreach and education activities

STEAM Education’s Engineering / Maths in a Box

I have found these classes hugely beneficial for improving my public speaking / presenting. Coming from an engineering undergrad, I am familiar with how to give a PowerPoint but

making a topic interesting and engaging requires a little more thought. Furthermore, having to stand-up in front of a class is an excellent way to overcome a fear of public speaking. I am far more confident now than I was when I started two years. The practice of slowly explaining quite complex principles, like how do boats float or planes fly, has greatly improved how I deliver my presentations. In the past I was always told I talk too fast, which was likely driven by my thumping heartbeat but now I can get up and comfortably speak on any topic.

'Climate Hack' Science Week 2019

During my previous experience with STEAM Education the material is prepared and ready for you, it's very easy, but with the climate hack I had to develop what was needed myself. This meant I had to think a lot more about what the activity was trying to achieve and how to actually run the sessions. One of the issues we encountered was that I placed too much emphasis on calculating CO₂ savings or the cost of solutions. The detailed information provided overwhelmed a lot of the students and they struggled with the calculations. I had prepared comprehensive information sheets in order to ensure they could get out real workable solutions. However, it was too much and students could not find the relevant data to perform the calculations, which meant they had to be walked through the calculations. In the larger school when we had 55 students, this was very difficult to manage, as I couldn't get around to all the groups.

Despite the difficulties, most of the groups managed to fully develop their ideas and the feedback received from teachers was very positive. I think the students appreciated that we were there to listen to their ideas rather than to tell them our ideas. I have learnt from the experience and am now developing a version for County Cork that will place more emphasis on student's creativity and less on calculations. The original format was far too technical, my aim had been to encourage them to think about engineering as an interesting career option, however, this is not what is important. Instead it would be more valuable to give the students the freedom to imagine innovative solutions to climate change.

Outreach at public events

Throughout the last few years, I have been continuously involved in outreach activities with my host institute the MaREI Centre; manning stands at the ploughing championship, during science week and a number of public events in Dingle (such as the LED bulb swap, Food festival, Tech week, Feile na Bealtaine). I happily volunteer my time for these activities because I think it is important that as experts we make ourselves available to the public and it

provides a very useful way of grounding oneself. Working within academia means that you are constantly surrounded by people obsessing over a topic, it is easy to forget that not everyone cares about climate change as much as you do. Therefore, it is beneficial to get out and listen to people's concerns and hear what their areas of interest are. This has helped me work on my language around climate change and reflect on ways on bringing people into a discussion about the topic. The scale and complexity of climate change makes it difficult for people to engage with, so it is important to relate the solutions to difficult challenges like sustaining our rural communities.

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STEAM Education Engineering in a Box - Eglantine primary school, Douglas, Cork, March – April 2018



STEAM Education Maths in a Box - St Mary's on the Hill, Hollyhill Cork, March – May 2018



'Climate change in a bottle' - Science Week, Western Gateway Building UCC, 17th November 2018



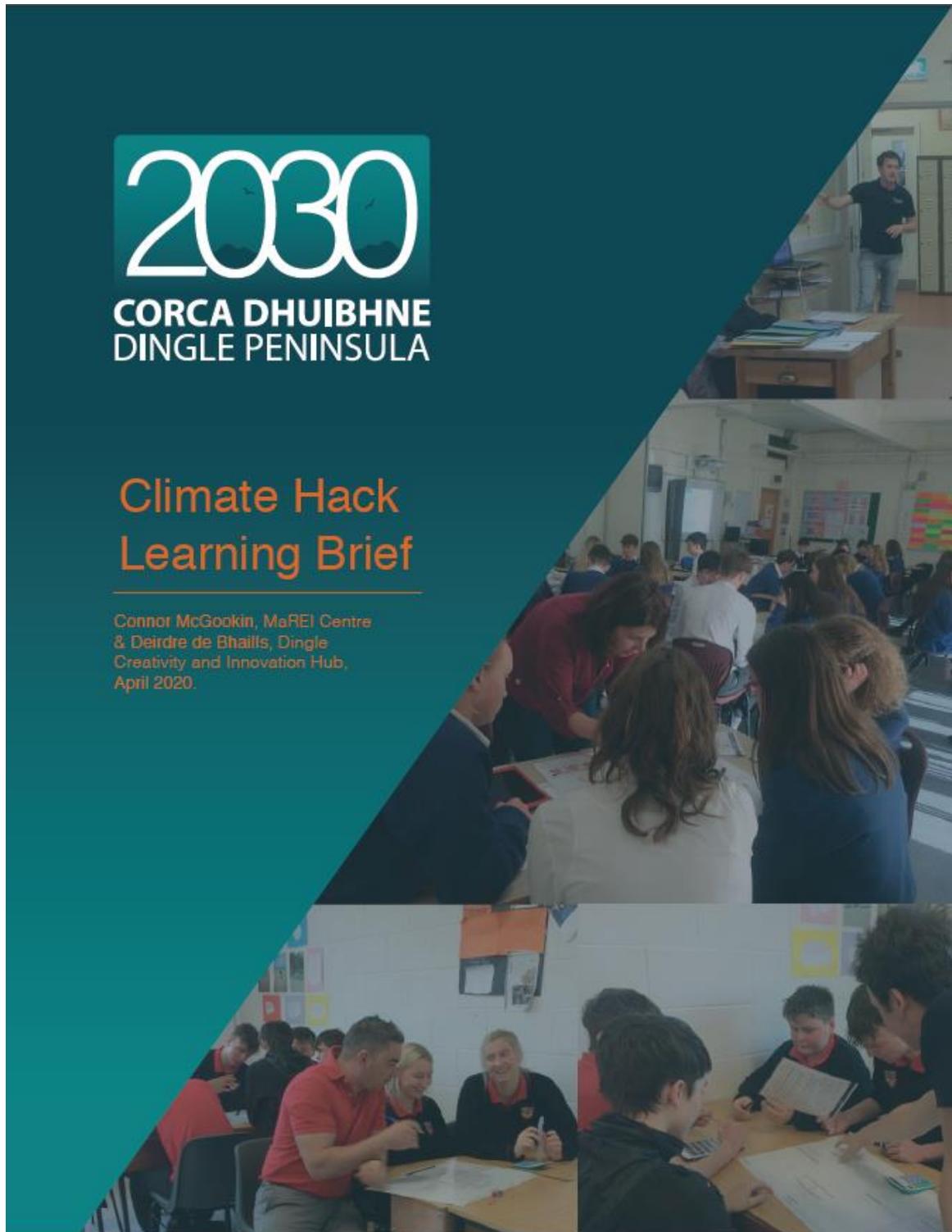
‘Climate Hack’ - Pobalscoil Chorca Dhuibhne, Castlegregory and Coláiste Íde, Dingle peninsula, 10th / 11th November 2019



‘LED bulb swap’ - Dingle Pobalscoil, 10th April 2019



Appendix 3.C Example of ‘learning brief’ co-produced with Dingle Peninsula 2030 partners



Background

The format of the event is based on the 'serious game' approach to scientific communication. A serious game is an interactive approach that is designed with the intention to teach rather than purely entertain. It is a very commonly used method of engagement in climate change research. [1] [2] [3] These games can help raise awareness, build capacity for problem solving and provide a space to explore potential futures. [4] A well-known example of the serious game approach is the World Climate Simulation, which asks participants to take on the role of UN negotiators and agree global climate change policy. [5]

The idea of the 'climate hack' template developed for the Dingle Peninsula was inspired by the work of Krzywoszynska et al. [6], Thomas et al. [7] and Volken et al. [8]. These studies all used some form of information sheets/cards to help participants make informed decisions about the future energy system. A similar approach was applied with the 'climate hack', an introductory brief on the current energy usage and associated CO₂ emissions, as

well as information sheets on the options available to decarbonise heating, electricity and transport were prepared. The purpose of providing this information was firstly to highlight the challenges facing the Dingle Peninsula and secondly to ensure that the students could make well-informed decisions about the future of their energy system.

This was an interactive outreach event to highlight the ongoing work of the Dingle Peninsula 2030 stakeholder group. [9] Dingle Peninsula 2030 is the umbrella title for the partnership formed between the Dingle Creativity and Innovation Hub, ESB Networks, MaREI and NEWKD. The ambition of the group is to support and enable the Dingle Peninsula transition to a low carbon future and to showcase the benefits achievable for rural Ireland in the process. The 'climate hack' was an important opportunity to highlight to young people the ongoing work to develop an energy master plan for the area as well as a number of exciting initiatives around; transport, bioenergy, co-operative ownership structures and sustainable farming.

Aims and Objectives

The overall aim of the event was to capture the key concerns of young people in the area. By giving them usable information and asking them to assume the role of a town planner, an interesting insight was gained into what parts of the energy transition they viewed as most important and their perceptions of the various solutions available.

The key objectives may be summarised as follows:

- Inform students of the current energy usage in their area, highlighting large sources of energy demand such as private car travel or home heating.
- Give students the necessary data on electricity, heating and transport energy options so they can make informed decisions about the future of their energy system.
- Capture the opinions and perspectives of young people.
- Develop local energy projects guided by young people's vision for a more sustainable future.

It was decided that the event would not be run as a competition but rather that following the event the most enthusiastic group from each school would be asked to develop their idea further and prepare a poster presentation to display at the public launch of the Dingle Peninsula Energy Master Plan. In the end, the best idea from each challenge was chosen, giving a presentation on a community solar farm, public transport and alternative sources of heat (anaerobic digestion and hydrogen from electrolysis).

How It Worked

The event was run as part of Science Week 2019 in collaboration with the Dingle Creativity and Innovation Hub. It involved a two-hour workshop with fourth and fifth year students in the three secondary schools on the Dingle Peninsula; Pobalscoil Chorca Dhuibhne, Coláiste Íde and Meanscoil Nua an Leith-Triúigh. The material used during the event can be found at www.marei.ie/dingle-peninsula-2030/, and below is a summary of the resources needed. In addition, there is a short-film of the event available on the Dingle Creativity and Innovation Hub's YouTube channel. [10]

Inputs

Person-hours	
Preparation*	24
Event	18
Total	42
Cost	
Translation **	€150
Printing & Co-ordination	€250
Video	€1,100
Travel & Accommodation	€160
Total	€1,660

*Preparation of the material and event organisation, excludes preparation time of the teachers / students
**Corca Dhuibhne is a Gaeltacht region, so all material was bilingual

The information on energy usage and alternative options for heating, transport and electricity was primarily based on the work of McGookin et al. [11], which also formed the basis of the Dingle Peninsula Energy Master Plan. [12]



Preparation

One week prior to the event, the introductory brief was sent out to schools. This gave an overview of how energy was currently being consumed in the region, how much this was costing the average household and the associated CO₂ emissions. It then prompted the students to investigate three key challenges facing the area; private car travel, home heating and electricity supply. In groups, the students were asked to choose one of these challenges or propose their own. A number of useful links were provided so that students could conduct their own piece of research in preparation for the event.

The Event

The event was run for 2 hours:

- 5 mins - Initial welcome address from Dingle Creativity and Innovation Hub.
- 10 mins – Introductory presentation from MaREI on the Dingle Peninsula energy balance and low carbon solutions in heating, transport and electricity.
- 1 hr 15 mins – Students were given the information sheet for their chosen challenge as well as an answer template with four sections to fill-in; CO₂ savings, cost estimate, potential barriers and benefits of their proposal. The data needed and example calculations were provided on the information sheet. In addition, tablet computers were available for further research.
- 30 mins – Each group was asked to present their idea(s).

Lessons Learnt

- Preparation is important – if students are given time to form groups and decide what they want to work on before the event then they get a lot more out of it.
- Demonstrator ratio - In order to ensure the students are given adequate attention and maintain focus throughout the exercise, it is best to have at least one demonstrator for every three groups of students.
- Not everyone is an engineer - The calculations should be simple, with easy to follow instructions. It is only necessary to give an overview of the relative cost of solutions in order to prompt a discussion about trade-offs like the fact that micro (domestic-scale) wind energy might be more popular but is not as cost effective as large (commercial-scale) projects.
- Focus on creativity - The solutions sheets should focus on developing an idea rather than calculating CO₂ savings or a cost estimate. The most important element of the event is to give young people an opportunity to make suggestions.

Outcomes



- The students presented their proposals as part of the Dingle Peninsula 2030 event on Feb 13th 2020, with an attendance of roughly 300 people.
- A group of students from Meanscoil Nua an Leith-Tríúigh, Castlegregory applied to the Friends of the Earth Solar PV competition.
- A Junior Cert Maths student used the template to develop an energy overview for their county as part of their CBA. Integrating the exercise into existing coursework presents an excellent opportunity to engage young people in climate change discussions.
- MaREI is working on refining the event material with a view to creating a national template.

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